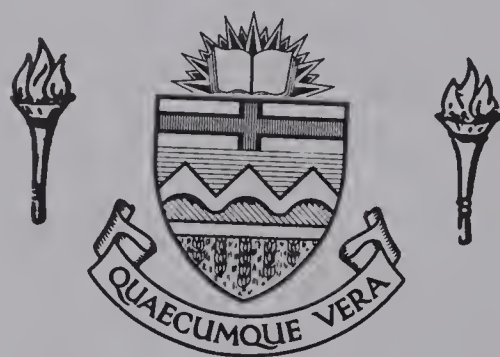


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A COMPUTER SIMULATION MODEL FOR
THE CITY OF EDMONTON SOLID WASTES COLLECTION SYSTEM

by



ROGER J. LAFLEUR

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF CHEMICAL AND PETROLEUM ENGINEERING

EDMONTON, ALBERTA

SPRING 1972

1972
75

THE UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A Computer Simulation Model for the City of Edmonton Solid Wastes Collection System" submitted by Roger J. Lafleur in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A computer simulation model of the City of Edmonton domestic refuse collection system is described. Example applications of this model are also given.

The construction of the model is detailed step by step, showing the derivation of the variables and mathematical functions comprising this model. The model consists of programs generating the quantities of solid wastes produced at a given time, generating the unit costs of collecting these wastes according to collection alternatives, and an optimizing program to select the best alternatives.

Simulation of the collection system is carried out and the direct operating costs are calculated according to the policy defined by the decision variables. The decision variables which may be the basis of the simulation experiments are: disposal site location, collection crew and vehicle performance factors and costs.

Example applications of the model are given wherein the number of disposal sites and locations are varied within the city. As well the system behavior under these conditions was projected to the years 1976, 1981 and compared to the base year 1970.

ACKNOWLEDGEMENTS

I wish to thank the many persons who contributed to this thesis by their help and encouragement:

Dr. D. Quon for his interest and assistance in this project.

The staff of the City of Edmonton, and especially Mr. W. Worton who freely provided data and information.

Professor P. Bouthillier who suggested the area of research.

The staff and my colleagues of the Department of Chemical and Petroleum Engineering for their help and encouragement.

Mrs. Mary Sherban for the excellent typing.

The National Research Council of Canada for their financial support.

I am especially grateful to my family for their wonderful moral support.

And finally to Ghislaine I owe the accomplishment of this project. Her interest and encouragement, though from afar, helped me carry it through.

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NOMENCLATURE

$A(i,j,t)$	Total loads disposed of from route i under alternative j for the week t .
$BCAPY(j)$	Capacity of the disposal site j for receiving refuse, in pounds per week.
$c_j(i)$	Fourier series coefficient for the j^{th} term.
$C(i,j)$	Cost per standard load of collecting a load from route i under alternative j .
$COLTI(i,j)$	Time required to collect a load under alternative j .
$CTIME(i)$	Time required to collect a standard 18 cu. yd. load in route i .
$d(i,t)$	Theoretical density of the collected refuse in 1000 lb. per standard 18 cu. yd. load.
$d^*(i,t)$	Actual density of refuse as given by raw data.
$D(i,j)$	L-metric distance between route i and disposal point j .
$Dist(i,j)$	Actual travelling distance between route i and disposal point j .
$FCTIM(j)$	Ratio of the time required to collect a load under alternative j to $CTIME(i)$.
$FLOAD(j)$	Ratio of weight capacity of a load under alternative j to that of a standard load.
i	Index representing the route.
$IWEEK$	Week in the year (e.g. 16 is the 16th week of NYEAR).
j	Index representing alternative for disposal.
$L(i,t)$	Total loads making up $W(i,t)$.
$NOHOU(i)$	Number of household equivalent units in route i .
$NYEAR$	Year for which model is operated (e.g. 1974).

$nw(i,t)$	Theoretical normalized weight per household-week as given by the truncated Fourier series.
$nw^*(i,t)$	Actual values of $nw(i,t)$ as given by the raw data.
n	Total number of routes.
m	Total number of alternatives available.
$PD(i)$	Population density factor of the route i .
R_k	Random number between 0 and 1.
$RCOST(j)$	Cost per unit time of crew under alternative j .
t	Time, assuming integer values giving the number of the week counting the first week of 1966 as $t = 1$.
$TCOST(j)$	Cost per standard load of post-treatment at disposal site j .
$TOSTT(i,j)$	Total time required to collect and transport a standard load equivalent from route i to disposal site j .
$TOTCO(t)$	Total cost of collecting the refuse from all routes during the week t .
$TOTTI(i,j)$	Total time required to collect and transport a load from route i under alternative j .
$TTIME(i,j)$	Time required to travel from route i to disposal point of alternative j , and return.
$u_d(i,t)$	Random deviation of $d^*(i,t)$ from $d(i,t)$.
$u_w(t)$	Random deviation of $nw^*(i,t)$ from $nw(i,t)$.
$w(i,t)$	Weight of refuse generated per household in route i for the week t .
$w^*(i,t)$	Actual $w(i,t)$ value as given by the raw data.
$\bar{w}^*(i,t)$	Actual values of $\bar{w}(t)$ for route i .
$\bar{w}(t)$	Theoretical 52-week average of the weight of refuse generated per household-week.
$W(i,t)$	Total weight of refuse generated in route i during week t .
$WTIME(j)$	Waiting time at disposal point j for dumping and crew rest break.

$x(i),y(i)$ Coordinates of route i .
 $x(j),y(j)$ Coordinates of disposal site j .
 $\phi_j(i)$ Fourier series phase angle constant for the j^{th} term.

CHAPTER I

INTRODUCTION

The management of the operations involved in disposing of society's solid wastes is an important function of municipal engineers today. This problem has become increasingly complex and expensive over the last few decades, and indications are that it will become even more so in the coming decades.

The problem of effectively disposing of the many solid wastes of an urban society is one bounded by many constraints, and more are continually added. Further, as an urban complex expands and population increases, the magnitude of the problem increases, not only because of extra wastes volume but also because of space requirements. In addition there is the trend to increased wastes generation as society becomes more affluent.

At the same time technological advances suggest new solutions to this problem, inbred urban expansion renders existing solutions obsolete. Management is thus continually faced with a changing situation, and to cope with this expanding problem it must always choose from among a number of alternatives.

This has always been a difficult task; and as the problems become more complex, exact definition and evaluation of the alternatives are likewise more difficult to establish.

To this end the computer has become an extremely powerful tool for modern management. Its capability of performing endless calculations, rapidly and accurately, permit the evaluation of many alternatives.

The city of Edmonton is an urban complex presently faced with the choice of a number of alternative solutions for the disposal of its solid wastes. In this respect it must find solutions to a disposal problem in which it must phase out an obsolete incinerator and in which it has exhausted the potential of the present landfill site. It is therefore faced with the problem of developing new ultimate disposal sites. As a result of rapid city expansion, these new sites will have to be located further from the city than the old exhausted sites.

This then is a problem not unfamiliar to most cities; more and more wastes are generated each year and the ultimate disposal must be carried out at greater distances from the points of generation. These factors increase the burden of the waste collection system. Thus management is caught in the squeeze between increasing requirements coupled with escalating costs and on the other hand the reluctance of the taxpayer to carry a larger financial burden.

Initially with small urban centers, solid wastes were disposed of within the city, near the outskirts in open dumps. Since then the urban centers have sprawled, popular environmental concern has risen and this old system has become obsolete. Thus the change has been from a form of near on-site disposal of the wastes generated, to a complex collection system transferring the wastes to remote disposal areas.

The city of Edmonton is presently coping with this change to remote disposal areas. As a result it has to consider a number of alternatives. The variety of possible alternatives and complexity of each indicate the usefulness of the computer as a tool for the solution of this problem.

Taking this approach a computer model of the city of Edmonton solid wastes collection system would be required. Such a model should be sufficiently flexible so as to be able to handle the different various inputs of every alternative. In this way, with a model of the actual system, various alternatives may be evaluated by simulating the system behavior under the alternative inputs.

To this end therefore, an actual simulation model of the city of Edmonton domestic refuse collection system has been constructed. The purpose of this model is to provide a tool for the evaluation of various alternatives. As a side benefit, it is hoped that this model will also provide insight into the workings of the actual system.

CHAPTER II

MATHEMATICAL MODELS

2-1 General

Mathematical models (17), (18), (19) describing actual physical systems have become very useful tools to the modern manager since the advent of the computer. The computer has permitted the construction and application of complex models, those requiring many interrelated calculations. At the same time it has greatly speeded up the applications of the models, thus allowing a great number of experiments to be performed on the model.

A mathematical model may be defined as a set of mathematical and logical equations that taken together, quantitatively describe a particular physical system.

The model is made up of the following elements:

- (a) Variables - quantitatively definable properties of the system which may assume different values.
- (b) Parameters - quantitatively definable constant characteristics of the system.
- (c) Mathematical Functions - the mathematical formulae relating the variables and parameters.
- (d) Logical Equations - the set of rules organizing the mathematical functions in a pattern such that they describe the physical system.

Thus the formulation of a model representing a certain system requires that the properties and characteristics of that system be recognized and identified. Secondly it must be possible to measure quantitatively these properties and characteristics, and thus assign values to them. Third, mathematical equations must be formulated to show the relationships that exist between the various properties and characteristics. Finally, a logical set of rules must show how these mathematical equations, variables and parameters are to be used to describe the system.

A valid representation of the system will be one where if a sufficient number of variables and parameters are assigned specific values, the others will have values defined by the model that are essentially the same as those of the real system under corresponding conditions. The above should hold in all cases of specified conditions.

Furthermore models may be classified according to the type of variables employed.

- (a) Deterministic models - the variables in the model are exact and do not contain random components. Thus the model functions do not include probability distribution functions.
- (b) Stochastic models - some of the variables include random components. Thus among the model functions are probability distribution functions.
- (c) Expected Value models - actually a stochastic model treated as a deterministic model by assigning expected values to the stochastic variables.

Thus for a given set of conditions or initial assignment of a sufficient number of variables, the deterministic and expected value models have a unique outcome, while the stochastic models have non-unique outcomes.

Finally models may also be classified according to the variable time:

- (a) Static models - are models in which the variable time has a constant value, or in this case is a parameter.
- (b) Dynamic models - are models in which time is a variable and thus may assume different values.

The mathematical model approach to problem solution is necessarily an idealized abstract conception of a real-world system. The actual system operates in a real environment under a great variety of different and changing conditions. The conception of a model therefore requires idealization of this system, abstraction of the important conditions and laws under which the system operates, and organization of these in a format which can be representative of this system. Thus the main conditions and laws are abstracted in a set of variables and functions determining the system behavior, the other minor conditions are lumped together and relegated to the status of random variables.

A first abstraction of a solid wastes collection system would be an idealized flow diagram as shown in Figure 2-1(a). The flow diagram may be considered as a general first level abstraction or a macro-concept of the system where a number of operations are lumped together. The basic

operation is the transfer of wastes from the source areas to the disposal areas or sinks. In this case the example is shown whereby the wastes from source 8 may be transferred to sinks 1, 2, or 3 with two modes available for the move from 8 to sink 1. The model would consist of a set of mathematical functions describing mathematically each transfer option, a set of input variables and a set of output variables. To borrow the nomenclature used in control engineering, the system would be described as a transfer function operating on an input variable vector to produce an output vector as shown in Figure 2-1(b).

The abstraction may be carried out to the more detailed level of a micro-concept of the system as shown in Figure 2-2(a). In this case the operations that were lumped together in the macro-concept are retained as separate operations. The basic operation is still the transfer of wastes from source to sink, but this basic operation is conceived as a set of sequential sub-operations. Again the model consists of a set of input variables and output variables, but now there are more sets of mathematical functions. In this case the system would be described by a multi-transfer function model, Figure 2-2(b).

The general model, with its lesser degree of details, would not be as sensitive as the micro-concept model. It would operate as an expected value model, relegating many of the variables which the second model considers explicitly to the status of random variables. Even then the second model, as an abstraction, would still contain a number of random effects. Thus a third and even more detailed model could be set up.

There are however disadvantages to a more detailed model. Much more detailed information is required, and as more variables are introduced they are of lesser and lesser importance, thus having less effect on the system behavior. The model becomes much more complex, more difficult to understand and more difficult to construct. In all cases of model construction there exists therefore a level of abstraction which will provide the required information with a minimum of effort.

2-2 Purpose of Models

The aim of model construction is two-fold, and both purposes should be considered important. The first is that a model serves as a teaching aid. The abstraction process of modeling allows the organization of the concepts describing the system, and this organization of thought should be used to understand more easily the real-world system so represented.

Secondly the model should serve as an experimental tool. If the model is a valid representation of the real system, it should be possible to operate this model under various conditions different from those now existing. Thus it would be possible to predict the system behavior without having to proceed to lengthy and costly real-world experimentation.

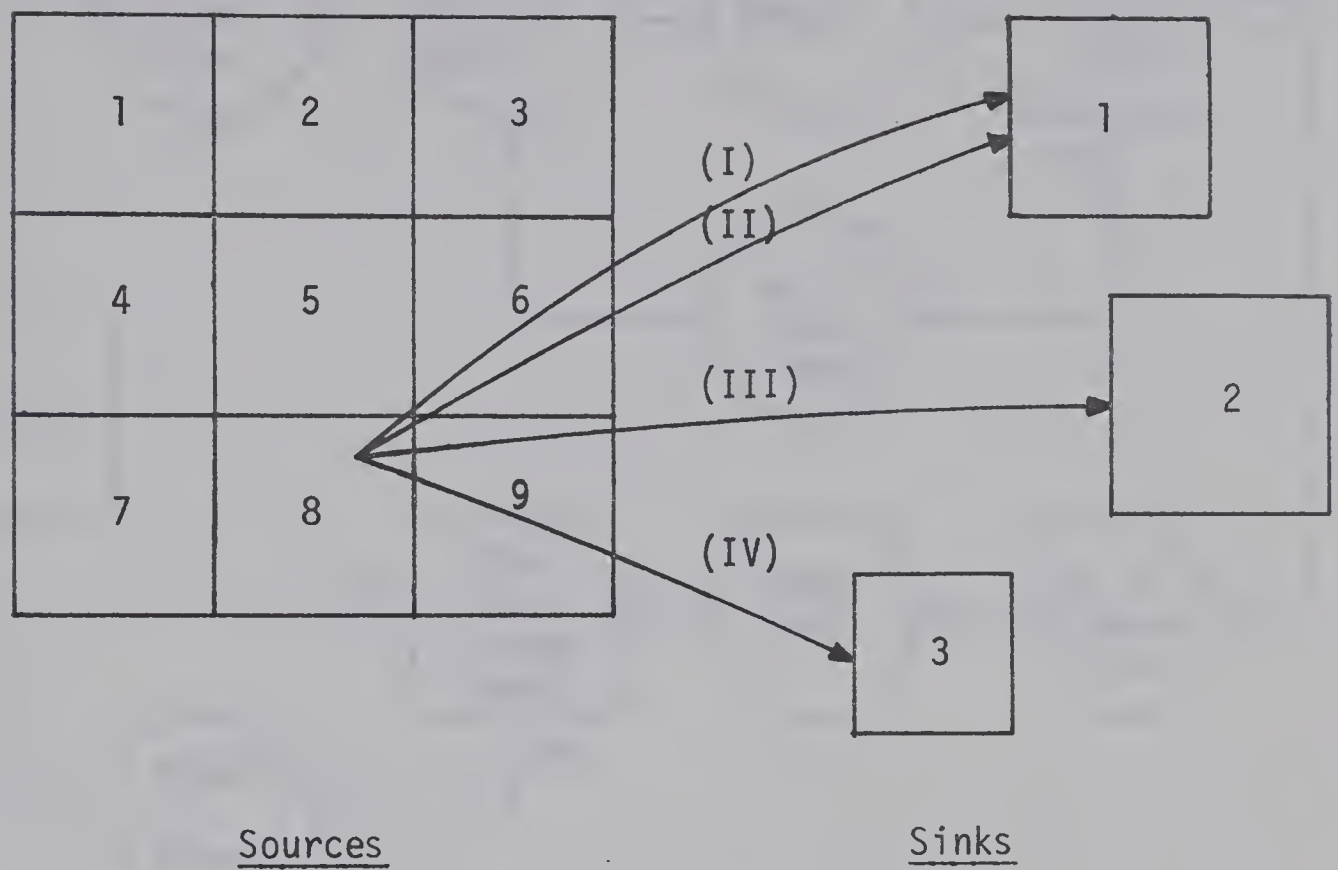


Figure 2-1(a)
Idealized Macro-Concept of Wastes Collection System

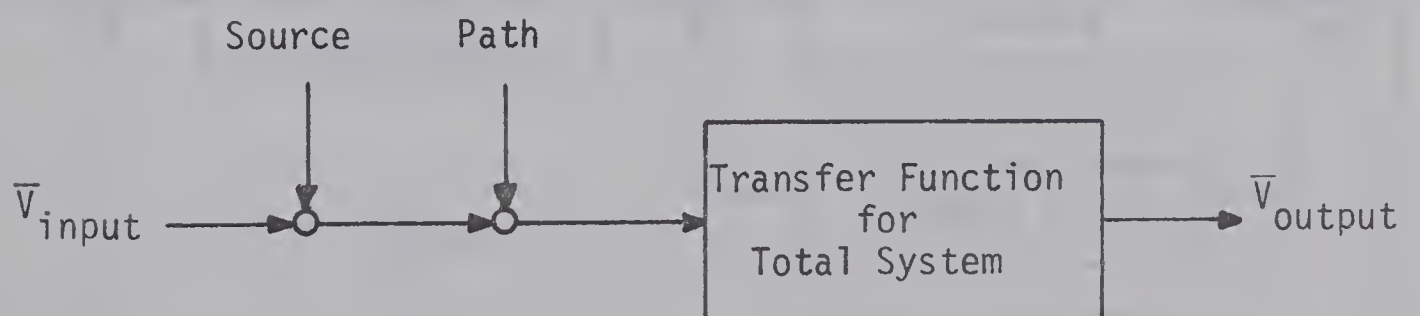


Figure 2-1(b)
Schematic Representation of Model of Macro-Concept

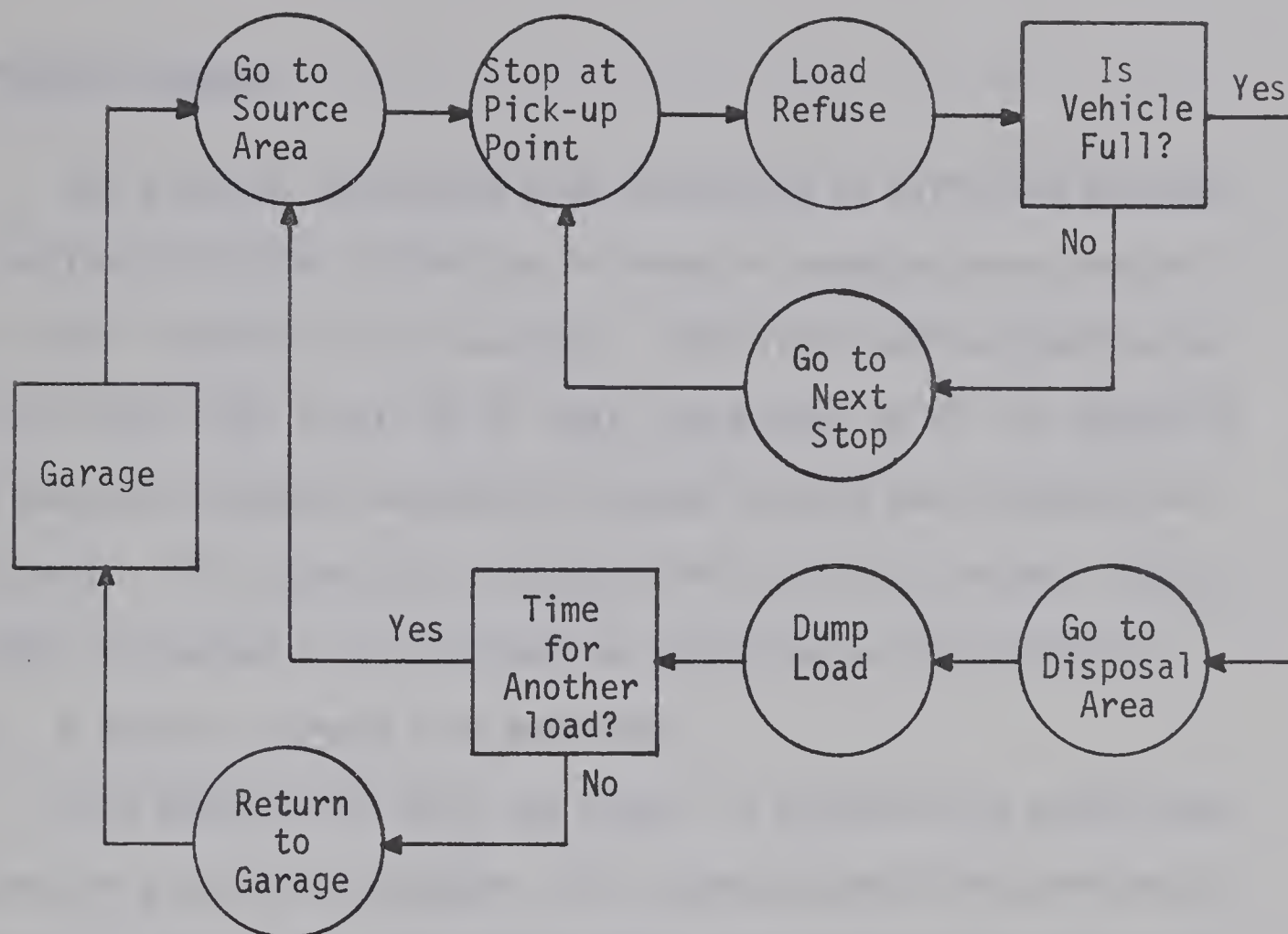


Figure 2-2(a)

Idealized Micro-Concept of Wastes Collection System

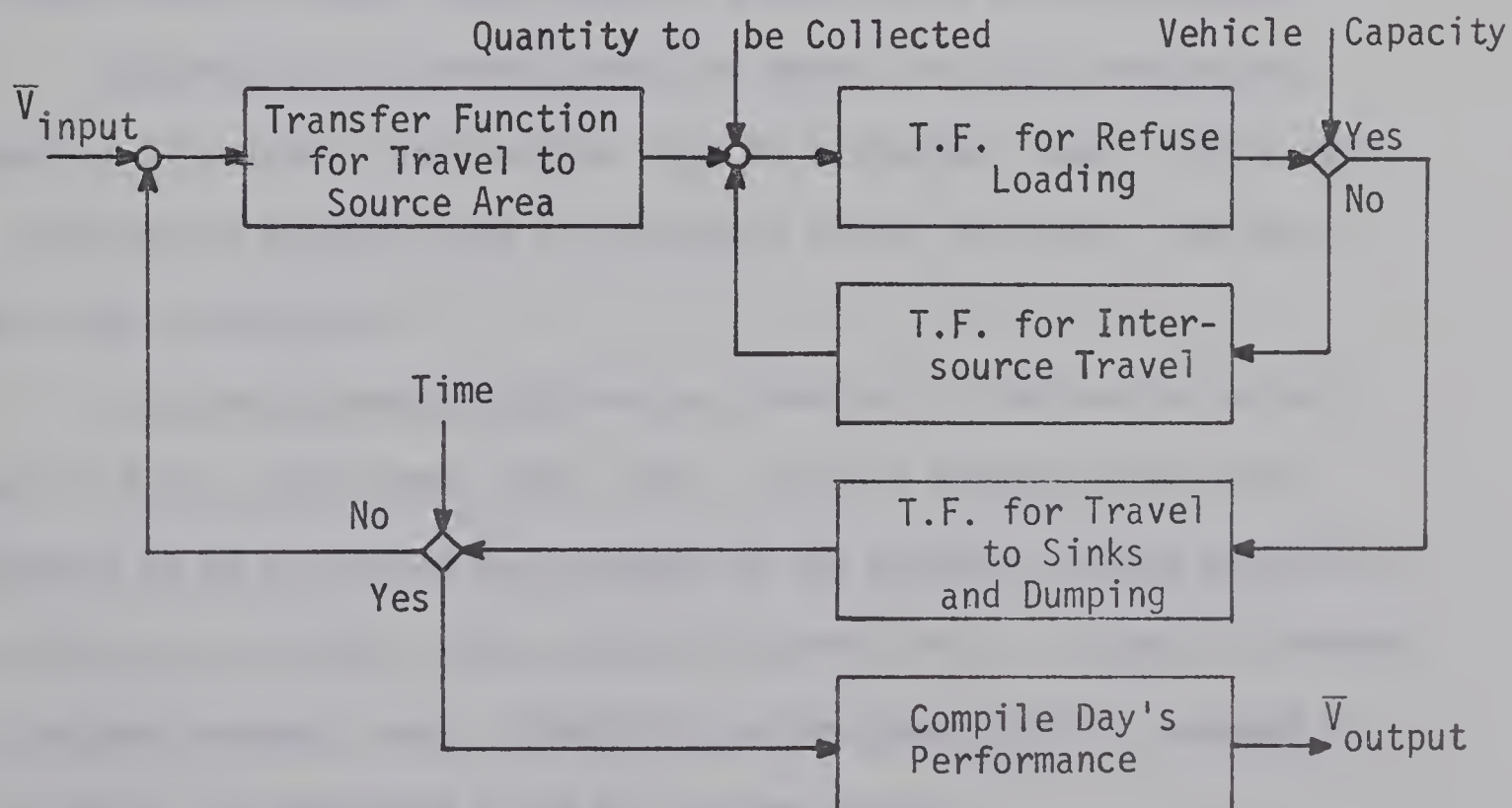


Figure 2-2(b)

Schematic Representation of the Micro-concept Model

2-3 Previous Studies

The problems associated with organizing an efficient municipal refuse collection system by the use of computer modeling have started to appear in the literature only recently. The first studies reported by Quon et al (22), (25) Truitt et al (29), and Bodner et al (5) adopted a total simulation approach whereby the system studied was simulated on a daily basis. This approach considered the collection process step by step: every collected load of refuse was simulated using stochastic factors. A typical day was thus generated.

This approach is valid and useful in establishing operational decisions for a particular system. This approach described previously as the micro-concept, has the disadvantage of requiring much input data. This is not serious if small collection areas are considered, but becomes more complicated if large areas such as a whole city are considered.

Secondly this approach does not have a built-in optimizing procedure. If various alternatives must be evaluated, every single case (or a significant sample) must be evaluated rather than only the best case of each alternative.

A second approach which we may consider as the macro-concept is that of Marks and Liebman (15), (16). In this approach the wastes are assumed to be collected and brought to the disposal points according to a certain cost vector. The collection operation is assumed to operate at a constant average level. Similarly wastes generation is assumed to be a constant as determined again by average values.

This second approach is thus a static model working on fixed expected values. Various alternatives are considered and optimized by use of linear programming methods.

In this study the approach for the proposed model will be generally the macro-concept. However the model is to be a dynamic one rather than static. Also the wastes generation process will be considered as a stochastic one. This approach is thus seen to be an extension of the Marks and Liebman model, bringing in more variables of a stochastic nature.

2-4 Model Construction Steps

The process of formulating a model to describe a specified real system is thus one involving a number of steps. The steps involved are oftentimes lengthy and may require a certain amount of feedback among them. This is even more so if the system is a complex one.

Regardless however of the model complexity, these are the following steps:

- (a) Definition of problem and system.
- (b) Collection of information and data, and identification of parameters and variables.
- (c) Establishment of a logical flow diagram of the model.
- (d) Determination of the mathematical relationships between the variables and parameters.
- (e) Formulation of the detailed model, in the case of a computer model, the program.

- (f) Testing and validation of the model.
- (g) Revision of the model.
- (h) Experimentation with the model.

For the report of this study these steps will be outlined as clearly as possible, and the model development will follow these lines. This is done in an effort to help the layman in understanding the work involved in model construction, and hopefully in a better understanding of this model and the model approach to problem solving.

CHAPTER III

THE CITY OF EDMONTON REFUSE COLLECTION SYSTEM

3-1 The Present System

The city of Edmonton assumes the responsibility for the collection, removal and disposal of all domestic refuse under its bylaw No. 1895. It may discharge this responsibility itself or grant contracts to private concerns for the collection of all or part of the accumulated domestic refuse. The collection and disposal of trade wastes (wastes other than those from private dwellings and apartments) are however the responsibility of those producing them. The city may collect and dispose of these wastes itself but for a fee.

The city's responsibilities in this area are carried out by the Sanitation Department. This department maintains a fleet of collection vehicles and crews for the collection of the refuse for which it is responsible. It also operates the disposal grounds and one incinerator.

It has retained the responsibility of refuse collection for the major part of the city. The North-west section comprising the old Jasper Place limits is serviced on a contract basis by a private firm. The part of the city serviced by the department has been divided into some 62 small areas called routes. The collection is carried out by a two man crew with an open non-packing 18 cubic yard truck servicing each of these routes. They may collect 4 to 8 loads per day depending on their distance from the disposal points. The crews work a standard 40 hour week with most of

the routes set up such that this is the usual time requirement. Collection is carried out during the daytime for about two thirds of the routes, while night collection is in effect for the central routes where daytime traffic is heavy. During periods of excessive refuse production additional crews are placed on the night shift.

The quantity of refuse and the time required for the collection of each load out of a route is entered into the records. This data is compiled on a weekly basis and this serves as the main cost control factor. The weekly basis is chosen as the required collection frequency is once per week, and thus lags or speed-ups do not affect the total record. A tight control is kept on the collection crews at the foreman level to maintain efficient collection. This is further rechecked in the weekly reports.

For the past few years disposal has been carried out by incineration and landfill. The incinerator with capacity for disposing of 1250 tons per week is located near the city center. Two landfill areas were in operation, the Beverly dump and the South-side dump. In December 1970 a transfer station equipped for refuse grinding with a capacity of 20 tons per hour was opened in the West-end. The location of these disposal sites is shown in Figure 3-1 which is a map of the present city limits upon which a coordinate system scaled in miles has been superimposed. The incinerator is located at the origin of the coordinates, the Beverly dump location is the point A, the South-side dump B, and the transfer station C. The location of the individual routes is given by their X-Y coordinate in Appendix D Table D-1.

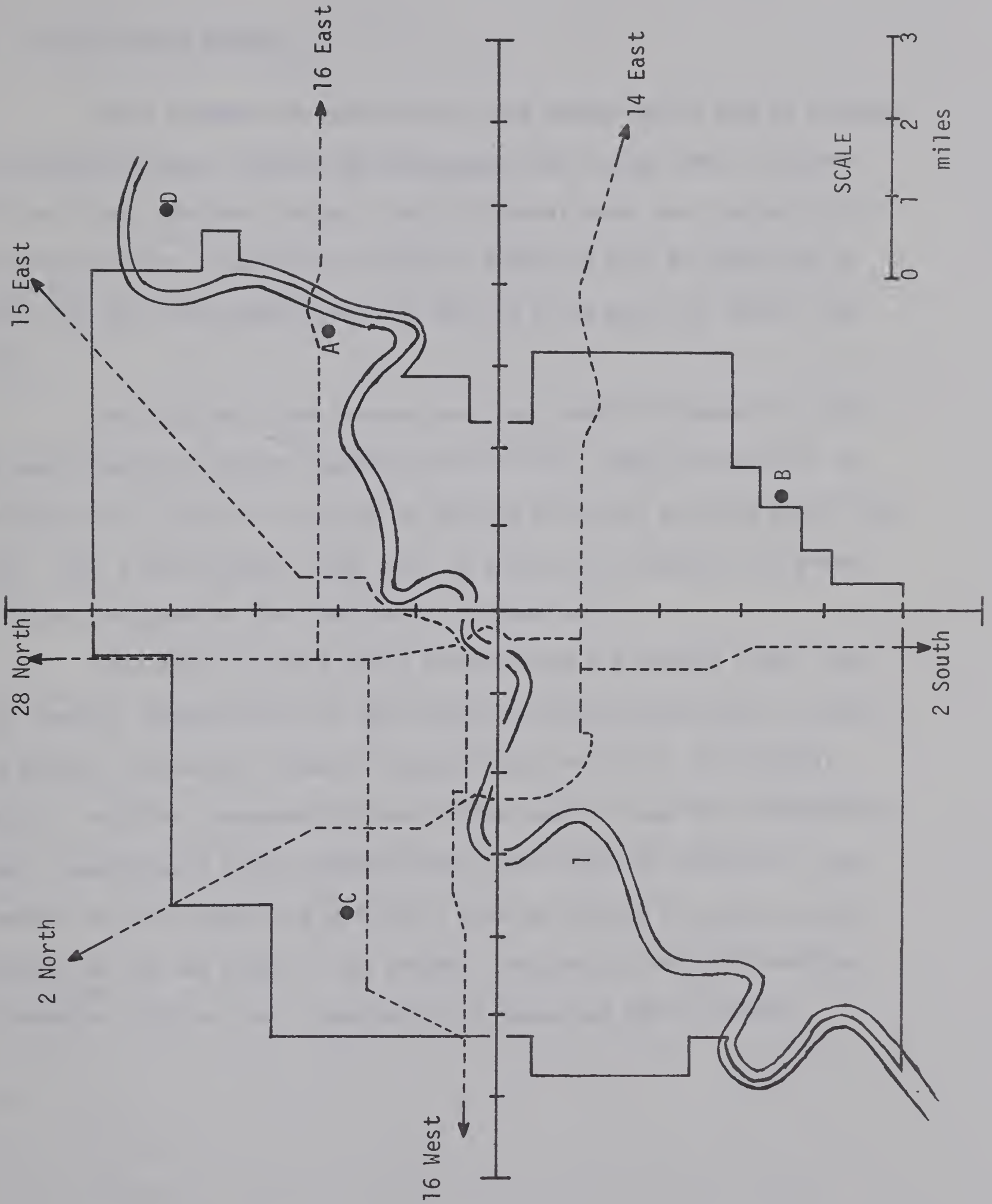


Figure 3-1
The City of Edmonton (1970 Limits)

3-2 Future System Changes

Major changes are occurring to this system mainly due to changes in disposal policy. Firstly the incinerator was closed down in October 1971 as it was obsolete, being a costly disposal means and causing an air pollution problem. Secondly the Beverly dump area will be exhausted in early 1972 while the South-side dump has but a few years of useful life left.

The city has opted towards sanitary landfill disposal as being the most practical disposal method at this time. Refuse grinding is to be carried out with this practice to achieve efficient and safe use of the site. Thus a new disposal site, with an estimated lifetime of 25 years, is to be developed at the location D in Figure 3-1.

This site is some 4 miles further than the Beverly site. This will involve reorganization of the present collection practices, as under the present system the refuse is transported directly to the disposal points. With the increased distance to the new site and loss of multiple sites, considerable extra transportation costs would be incurred. Thus a number of new options are available, such as the use of packer-trucks carrying to the new site, or the present low-capacity vehicles carrying to transfer stations, or a combination of these and other options.

CHAPTER IV

MODEL CONSTRUCTION

4-1 Variable and Parameter Identification

A refuse collection system is essentially the inverse of a goods distribution system. This being the case, it is expected that the variables and parameters used to describe the two systems would be similar. In fact whereas a goods distribution system may be described as a demand activated system, a refuse collection system would be a supply activated system. In both cases the problem is the same: moving materials from sources to sinks. In one case there are few sources and many sinks, in the other many sources and few sinks.

In considering a collection system operating under various policies or alternatives, the system may be thought of as a move from source to sink with various paths available. The paths in this case are the different alternatives available. There are certain variables and parameters associated with the sources, others with each of the paths and finally another set associated with the sinks.

For a refuse collection system the following variables and parameters may be defined. The classification used is that described by Naylor (18) where the exogenous variables are defined as variables which act upon the system, but are not acted upon by it. Status variables are those which define the state of the system at a certain time, and the endogenous variables are the output variables of the system.

Exogenous Variables:

1. Environmental:

Population density of sources.

Number of household units in sources.

Spatial location of source.

Travel time required for round trip between source and sink.

Collection time required per unit of refuse.

Unit cost of collection and transportation under alternative j.

2. Decision:

Type of collection vehicles.

Performance factors of vehicles.

Capacity of vehicles.

Spatial location of sink.

Capacity of sink.

Status Variables:

Weight of refuse generated per household.

Density of refuse.

Endogenous Variables:

Total cost of collection and transportation of all refuse
from sources to sinks.

Quantity of refuse collected under each path option.

4-2 Logical Statement of Model

The purpose of a mathematical model construction of a solid wastes collection system is the evaluation of various alternatives and thus optimization of the system. The optimization criteria in this case is taken as resource requirements: labor, equipment, land etc. Translating these resource requirements to a common denominator, dollars and cents, the criteria is then simply total cost minimization.

There are always questions as to what are the true total costs of a system. The problem usually results from the difficulty of assessing the indirect costs, identifying them and assigning values. For this reason, the model to be constructed here will only consider the direct costs of collection. This approach is simpler in that the overall problem of determining true resource requirements may be broken down into different parts, with the model providing, in this case, the part containing the direct costs.

The model thus serves to provide an input for subsequent optimization of the overall wastes collection and disposal system. Overall system optimization would have to consider operating and amortizing costs of the ultimate disposal sites, amortization costs of the collection service, and the quality level of service provided.

A general description of the proposed model may thus be stated as follows and as shown on Figure 4-1.

(a) Calculation of the quantity of wastes to be collected.

A first part of the model would be a generator that would determine the amount and spatial distribution of the refuse that is produced per unit of time. In this case the time unit is chosen as one week. The output variables of this generator would thus be the total weight and total number of standard loads produced each week by each refuse production area. These variables would be calculated according to the values of the input parameters.

(b) Calculation of the unit costs associated with each collection alternative.

A number of different alternatives are usually available in a collection system. For example many systems operate with two or more disposal points. Each collection alternative has a certain cost, resource requirement, associated with it which are functions of various parameters such as type of equipment, time required for collection of refuse, time required for transportation, etc. Thus for each production area a different cost would be calculated according to each collection alternative. The output variables of this cost generator would thus be a cost matrix.

(c) Determination of optimum policy.

With a number of alternatives available for the collection of refuse from each production area, the system may operate in a great number of different states. However there will be an optimum state where the costs are minimized. Thus a third part of the model

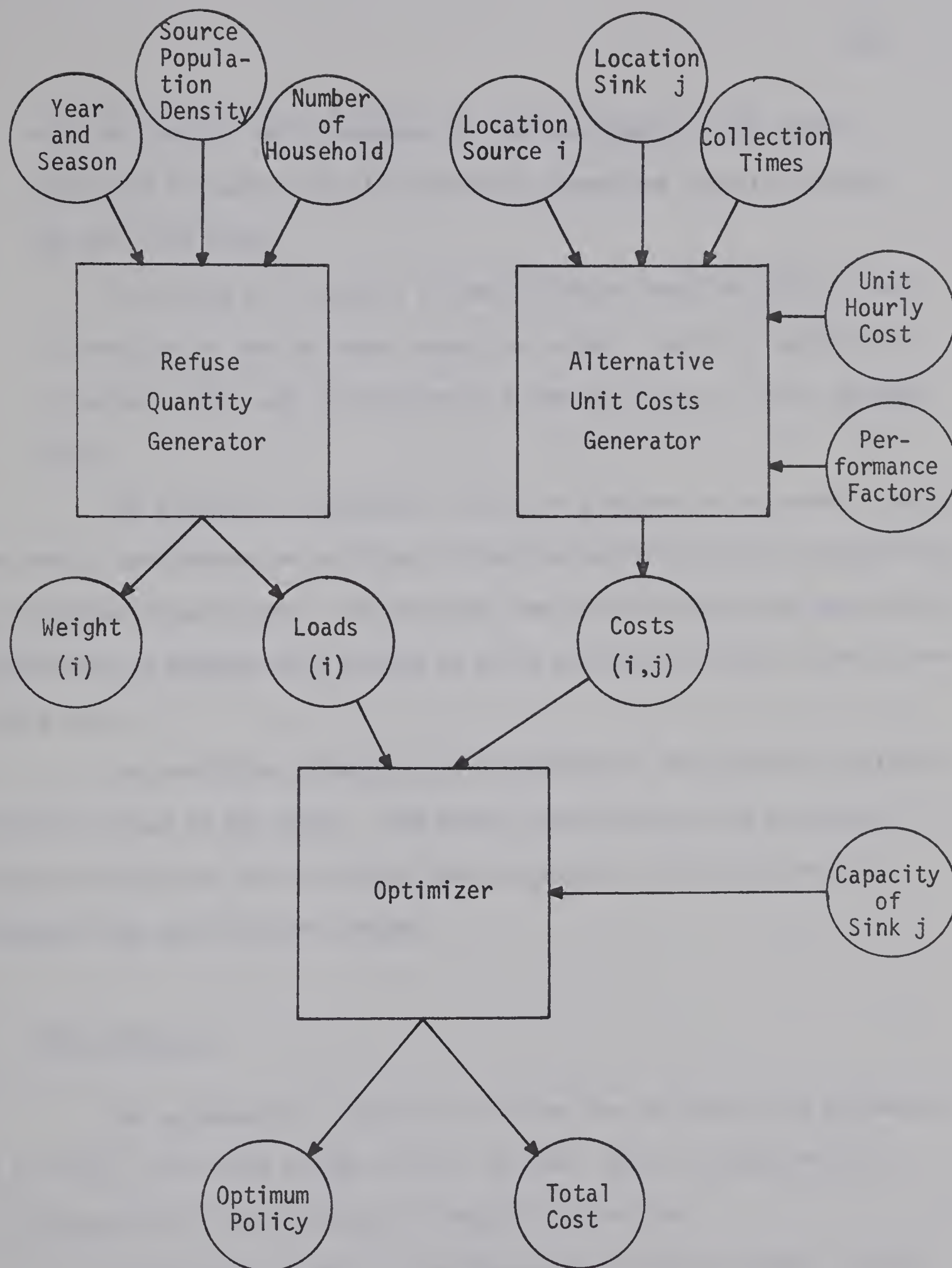


Figure 4-1
Generalized Model Flow Diagram

will be one that will generate the optimum state of the system.

The input variables are the previously generated quantity vectors and the cost matrix.

The output will consist of the optimized decision policy (what alternative to use for each production area), the total quantities collected under each alternative and the total cost of this optimum policy.

The purpose of the model is thus to simulate on an overall scale the weekly performance of a refuse collection system with the availability of different alternatives. At the same time it will choose the best policy under which to operate this system so as to minimize the total direct operating cost.

The available alternatives are defined by the decision variables which are input to the model. The model then simulates the collection system according to the decisions taken regarding collection vehicle, disposal type and location choices.

4-3 Data Analysis

The mathematical functions relating the variables and parameters of a refuse collection system are for the most cases non-deterministic. This requires the determination of empirical functions.

In the case of the city of Edmonton collection system, fairly extensive data was available covering the years 1966 up to 1970. This data included the following items, all recorded weekly:

- (a) The total loads collected each week from each route.
- (b) The number of loads dumped at the incinerator.
- (c) The number of loads dumped at the landfills.
- (d) The true weight of the loads dumped at the incinerator.
- (e) The estimated weight of the loads dumped at the landfills by assuming 3000 lb. per load.
- (f) The total collection and travel time required for these loads.
- (g) The total travel time required.

Actual data was thus available to estimate the system variables pertinent to this system. This data was extensive, on a weekly basis, covering a five year period for all of the city routes.

However the true weight was only recorded at one disposal point, and furthermore it was found that the assumption of a constant weight per load was not valid year round, though it was near the yearly average. Thus reliable weight data was only available for those routes which regularly used the incinerator. These routes were the North-west and South-west routes along with some North-central and South-central routes.

In order to analyze this data representative routes were chosen among those for which reliable weight data existed, the criteria being that at least 75% of the total loads during the year had been actually weighed. Unfortunately most of these routes are West-side routes, consisting of relatively more recent housing and including generally a more affluent segment of the population. However it was possible to cover a good part of the population density range using these routes.

The sample routes chosen for analysis were the following:

Route No. 1 - Laurier Heights

3 - Between 91 and 102 Ave. and 142 and 149 Str.

7 - Between 107 and 111 Ave. and 121 and 141 Str.

30 - Between 104 Ave. & River and 109 and 121 Str.

31 - Between 104 and 109 Ave. and 101 and 121 Str.

42 - Between 76 and 88 Ave. and 95 and 102 Str.

47 - Between 82 and 98 Ave. and 75 and 85 Str.

These routes were chosen to cover the population density range as best as possible and are considered to be fairly representative of the city as a whole. The exception is Route No. 1, which is one of the very affluent sections of the city, consisting of expensive single family homes sitting on relatively larger lots.

For each of the above sample routes the following data was extracted and analyzed:

- (a) The total loads collected per week.
- (b) The average density of these loads, calculated by dividing the total true weight disposed of at the incinerator by the number of loads this represented.

Thus it was assumed that for a given week and route the average density of the refuse disposed of at the landfill areas was the same as that disposed of at the incinerator.

Also available was data permitting the calculation of certain parameters of each route, this data being:

- (a) Number of household equivalents for each route.
- (b) The number of apartment building stops.
- (c) The number of trade wastes pick-ups per week.
- (d) The total number of cans at the apartment stops.

From this data a parameter representing population density may be calculated. For apartment buildings, a factor of two cans is considered to be one household equivalent unit. This factor was derived from experience and assumes that sufficient cans (a standard 4 cu. ft. refuse container) are available for the weekly refuse production. For trade wastes pick-ups a factor of one pick-up stop per week was assumed to represent two household equivalent units.

Using this data a parameter representing population density was derived. Generally a high proportion of apartment households, as compared to single dwelling households, indicates a high population density. Therefore the population density parameter (PD) is defined as the percent apartment and trade wastes household equivalent units. The calculation of this parameter is shown in Table 4-1, where a value of $PD = 0$ indicates an area composed solely of single dwellings, and $PD = 100$ indicates only apartment and trade waste household equivalents.

TABLE 4-1

CALCULATION OF POPULATION DENSITY PARAMETER (1970 DATA)

Route	Number of Household Equivalents	Number of Apartment Stops	Number of Cans (Apt.)	Number of Apt. Hou. Equivalents	Number of Trade Stops Per Week	Number of T-W Hou. Equivalents	Total Apt., T-W Hou. Equ.	PD(i) Percent Apt. T-W Hou.
1	994	0	0	0	0	0	0	0.0
3	1160	3	13	7	12	24	31	2.7
7	1763	23	397	199	20	40	239	13.5
30	1249	108	1534	767	48	96	863	69.0
31	1613	143	2334	1167	105	210	1377	85.5
42	1830	57	718	359	48	96	455	24.8
47	1841	11	520	260	11	22	282	15.3

4-4 Analysis of Weight Data

The weight-time curves for the five year period are shown in Appendix C, Figures C-1-1, C-7-1. These represent the extremes that are exhibited by the sample routes. It is noted that the weight per household-week ($w(i,t)$) is a periodic time series following a cyclical pattern, being low in winter and high during the summer season. In addition a few super-imposed peaks may be noted, namely during the Christmas season, others for spring clean-up and fall clean-up. Comparison of the curves also reveals the large summer-winter cycle for routes with smaller population densities (Route No. 1) where summer refuse production is about twice that of winter due to lawn and yard wastes, and also the greater clean-up opportunities in summer. In the case of greater population densities (Route No. 30) the summer-winter cycle is barely discernable.

Also these curves show an overall increasing trend in the total weight of refuse generation. Thus the variable $w(i,t)$ has a double dependence upon the time variable t , in one case an overall average increase with time, in the other case a cyclic seasonal.

4-4-1 Trend Equations

In order to extract the periodic dependence, the trend component of the time curve was first calculated and removed. The trend was calculated by the use of a 52-week moving average ($\bar{w}$) which is defined as:

$$\bar{w}(i,t) = \frac{1}{52} \sum_{t'=t-26}^{t+25} w^*(i,t') \quad (4-1)$$

$$t' = 27 \text{ to } 235 \quad (4-2)$$

This moving average is also shown in Appendix C. In these figures the overall increasing trend is now obvious. Secondly the function representing these curves would seem to be a simple first order linear one. Thus an equation:

$$\bar{w}(i,t) = a + bt \quad (4-3)$$

was fitted to these curves for the sample routes by least squares. The values of the calculated constants are given in Table 4-2, along with the correlation coefficients.

It would be thought that this trend would perhaps follow an exponential increase rather than a straight linear one, reflecting the exponential increase in consumer spending etc. seen in this century. Thus a second fit was also obtained by least squares where:

$$\bar{w}(i,t) = a'e^{(kt)} \quad (4-4)$$

The values of these calculated constants are also given in Table 4-2.

Examination of the correlation coefficients indicate that both fits are approximately equally good, perhaps favoring slightly the linear

function. In view of the short period involved it is not surprising that it is difficult to distinguish between the two fits as the first order linear equation is a first order approximation of the exponential equation if equation (4-4) is represented as:

$$\bar{w}(i,t) = a' \left[1 + kt + \frac{(kt)^2}{2!} + \frac{(kt)^3}{3!} + \dots \right] \quad (4-5)$$

If we assume the average value of $a = 45.2$ and $k = 0.00095$, the following series is obtained:

$$\bar{w}(i,t) = 45.2 + 0.043t + 0.00092t^2 + 1.3 \times 10^{-5}t^3 + \dots \quad (4-6)$$

For the five year period, the maximum value of t being 260 (weeks) this is not enough to make the second and higher order terms of sufficient magnitude to move the curve away from the heavy first order dependence.

Simply stated, the five year period over which data is available is not long enough to enable the determination of an exponential behavior.

This being the case, the modeling function for the variable $\bar{w}(i,t)$ will be taken as the average of the first order linear constants, excluding those of Route No. 1 from the average as being exceptions..

Thus:

$$\bar{w}(t) = 45.79 + 0.047 \quad (4-7)$$

$$t = 1 \quad \text{is the first week of 1966} \quad (4-8)$$

$$t = 260 \quad \text{is the last week of 1970} \quad (4-9)$$

TABLE 4-2
CALCULATED LEAST SQUARES EQUATION
COEFFICIENTS FOR THE VARIABLE $\bar{w}(i,t)$

A - For the fitted equation: $\bar{w}(i,t) = a + bt$

Route	a	b	Correlation Coefficient	Relative Std. Deviation
1	64.17	0.056	0.939	1.69%
3	45.04	0.077	0.952	2.68%
7	40.36	0.048	0.089	3.20%
30	48.67	0.041	0.910	2.08%
31	45.56	0.056	0.943	2.29%
42	49.47	0.021	0.906	2.53%
47	45.68	0.033	0.729	3.81%
Average	45.79	0.047		

B - For the fitted equation: $\bar{w}(i,t) = a'e^{(kt)}$

Route	a'	k	Correlation Coefficient	Relative Std. Deviation
1	64.1	0.00078	0.916	1.70%
3	45.6	0.00142	0.944	2.77%
7	40.6	0.00101	0.884	3.00%
30	48.5	0.00077	0.884	2.16%
31	45.6	0.00105	0.930	2.25%
47	45.6	0.00065	0.706	3.81%

4-4-2 Periodic Components

If the actual $w^*(i,t)$ curves are divided through by the average trend values $\bar{w}(i,t)$ a normalized weight per household-week curve results, free from all trends, leaving only the cyclic component of the time series.

This has been done and is shown in Appendix C where the normalized weight time series are given. The normalized weight per household-week is defined as:

$$nw^*(i,t) = \frac{w^*(i,t)}{\bar{w}(i,t)} \quad (4-10)$$

It is seen that the normalized curves fluctuate about the value of 1.0 as expected, and that the overall trend is quite well removed.

Purely cyclic curves of such types may be fitted by the use of Fourier series. In this case the period of the cycles is obviously 52 weeks, and the data covers five years or 260 weeks. Thus the series may be fitted over five complete cycles.

For a series of 52 points per cycle the Fourier series would have a maximum of 52 constants. Fortunately this series may be fitted by the least squares technique which does not involve solving a matrix, since it produces a diagonal matrix. This results from the fact that all non-diagonal elements of the least squares matrix are zero, as they are of the form:

$$\sum_{t=1}^N \cos\left(\frac{2\pi}{p} kt\right) \sin\left(\frac{2\pi}{p} mt\right) = 0 \quad (4-11)$$

if $k \neq m$

$$N = \text{integer multiple of } P$$

Thus the fitted equation of the normalized weight is:

$$nw(i,t) = a_0(i) + \sum_{j=1}^{26} a_j(i) \cos \left(\frac{2\pi}{P} jt \right) + \sum_{j=1}^{26} b_j(i) \sin \left(\frac{2\pi}{P} jt \right) \quad (4-12)$$

$$P = 52 \text{ weeks} \quad (4-13)$$

and the constants $a_j(i)$ and $b_j(i)$ are given by:

$$a_j(i) = \frac{2}{260} \sum_{t=1}^{260} nw^*(i,t) \cos \left(\frac{2\pi}{52} jt \right) \quad j = 1, 25 \quad (4-14)$$

$$b_j(i) = \frac{2}{260} \sum_{t=1}^{260} nw^*(i,t) \sin \left(\frac{2\pi}{52} jt \right) \quad j = 1, 25 \quad (4-15)$$

$$a_0(i) = \frac{1}{260} \sum_{t=1}^{260} nw^*(i,t) \quad (4-16)$$

$$a_{26}(i) = \frac{1}{260} \sum_{t=1}^{260} nw^*(i,t) \cos \left(\frac{2\pi}{52} 26t \right) \quad (4-17)$$

$$b_0 = 0 \quad (4-18)$$

$$b_{26} = 0 \quad (4-19)$$

Therefore using this technique the Fourier series coefficients were calculated for the normalized weight data of the 7 sample routes. The calculated coefficients are given in the appendix. It may be noted that the coefficient a_0 which is the mean of the normalized weights is 1.0, thus a good indication of trend removal.

The Fourier series may be expressed in another form:

$$nw(i,t) = a_0(i) + \sum_{j=1}^{26} c_j(i) \cos \left(\frac{2\pi}{52} jt - \phi_j \right) \quad (4-20)$$

$$\text{where: } c_j(i) = (a_j(i)^2 + b_j(i)^2)^{1/2} \quad (4-21)$$

$$\phi_j(i) = \tan^{-1}(b_j/a_j) = \sin^{-1}(b_j/c_j) \quad (4-22)$$

Using this second form it was noticed that certain of the coefficients $c_j(i)$ could be related to the population density parameter PD. This relationship is simply that routes with low PD values show greater seasonal fluctuations, thus have larger $c_j(i)$ values.

Secondly only some of the lower j value coefficients show this effect. This is to be expected as the higher j value coefficients are those of the higher frequencies and as such may simply be noise or random fluctuations, whereas the lower frequencies (low j 's) are the truly seasonal, long period fluctuations.

Thus for the coefficients c_j , $j=1$ to 10 a first order linear function was calculated, again by least squares, relating them to the parameter PD. Again the data from Route No. 1 was excluded. These functions may be defined as:

$$c_j(i) = a + b (PD_{(i)}) \quad (4-23)$$

Also it would be expected that the phase angle term ϕ_j would be constant for all i as this term only represents the phase lag of the seasonal cycles and this is independent of the population density, being only a factor of the climate.

The values of the calculated constants for these fitted equations are given in Table 4-3. As well the values of $c_j(i)$ are plotted versus $PD(i)$ in Figure 4-2 for $j=1$ to 6. Similarly the calculated average values of ϕ_j are given in Table 4-3.

It is seen that the values of ϕ_j are in fact quite constant for those values of j where $c_j(i)$ shows a strong correlation with $PD(i)$. Also the term $c_j(i)$ for $j=1$ proves to be nearly zero with $PD(i) = 100$, i.e. when the route is composed of 100 percent apartment and trade wastes stops, there would be no summer-winter fluctuations.

The modeling function for the normalized weights has been chosen as the Fourier series including only the terms for $j=1,2,3$ and 5. All of the other terms have been dropped. This results in a fairly good approximation of the full 26 term series, producing a smooth cyclic curve with a minimum number of terms. Example curves for the two series are shown in Appendix A for Route No. 3.

TABLE 4-3

FOURIER SERIES COEFFICIENTS AS FUNCTIONS OF PD(i)

A - Least Squares Coefficients of Equation: $c_j(i) = a_j + b_j PD(i)$

j	a_j	b_j	Correlation Coefficient	Relative Std. Dev.
1	0.2885	-0.002710	-0.979	11.7%
2	0.0923	-0.000669	-0.924	15.0
3	0.1104	-0.000801	-0.936	17.1
4	0.0258	0.000033	0.134	29.0
5	0.0384	-0.000244	-0.906	16.9
6	0.0343	-0.000116	-0.715	11.5
7	0.0189	-0.000025	-0.218	20.0
8	0.0269	-0.000217	-0.763	26.8
9	0.0186	-0.000022	-0.096	39.3
10	0.0177	-0.000105	-0.571	29.7

TABLE 4-3 (continued)
FOURIER SERIES COEFFICIENTS AS FUNCTIONS OF PD(i)

B - Average Value of ϕ_j , being constant for all PD(i).

j	Average ϕ_j	Correlation Coefficient	Absolute Std. Dev.
1	3.522 rad.	-0.088	0.146 rad.
2	4.410	-0.409	0.204
3	1.072	-0.679	0.187
4	1.290	-0.273	0.229
5	0.445	0.308	0.446
6	5.753	-0.276	0.180
7	1.312	0.293	0.573
8	2.350	-0.025	0.664
9	0.653	0.0745	0.304
10	0.528	-0.226	1.075

$$\text{Full Cycle} = 2\pi = 6.28$$

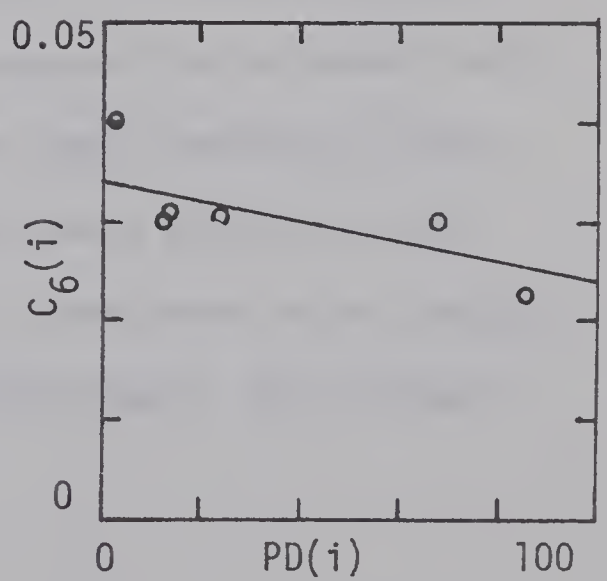
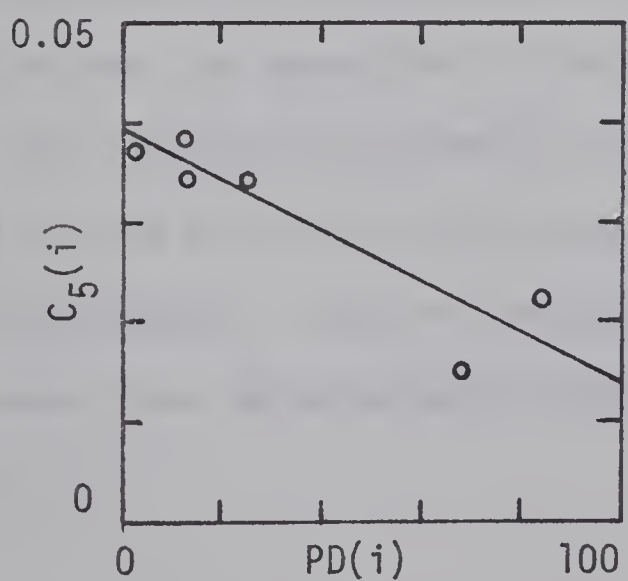
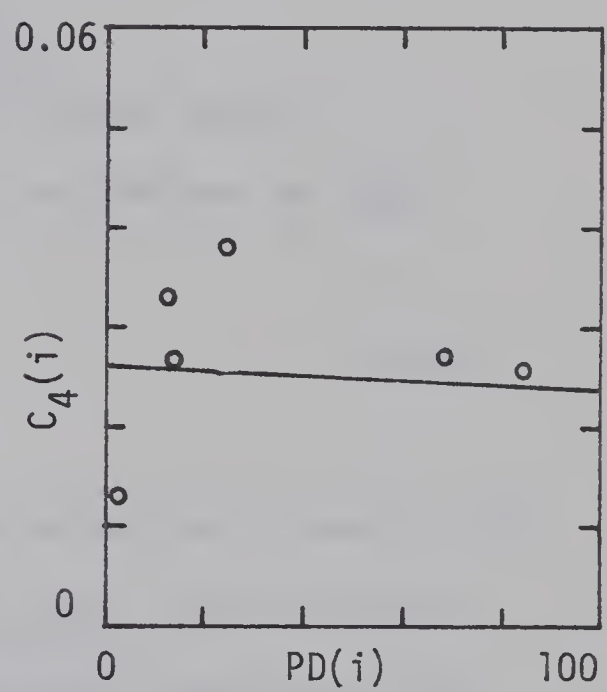
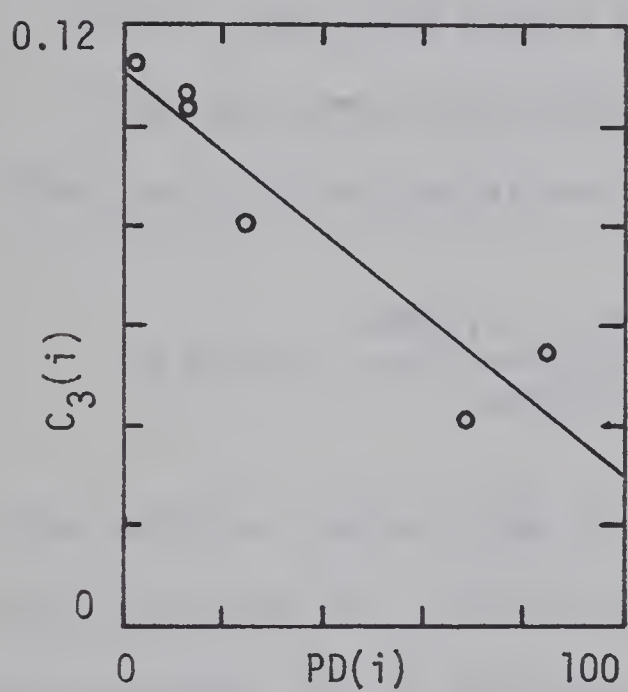
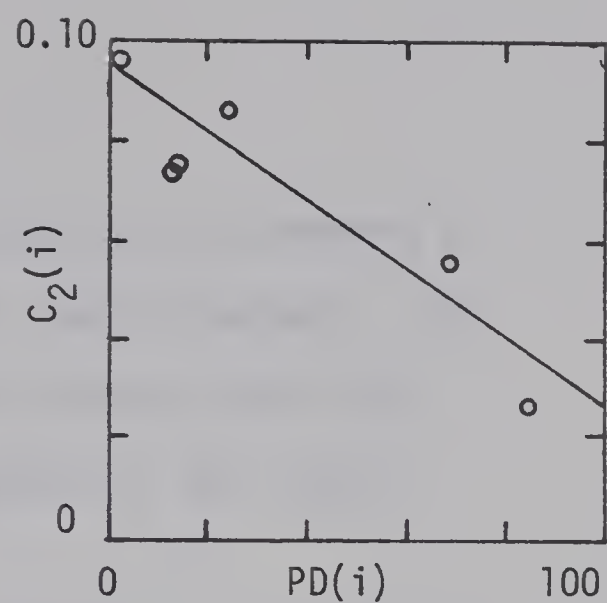
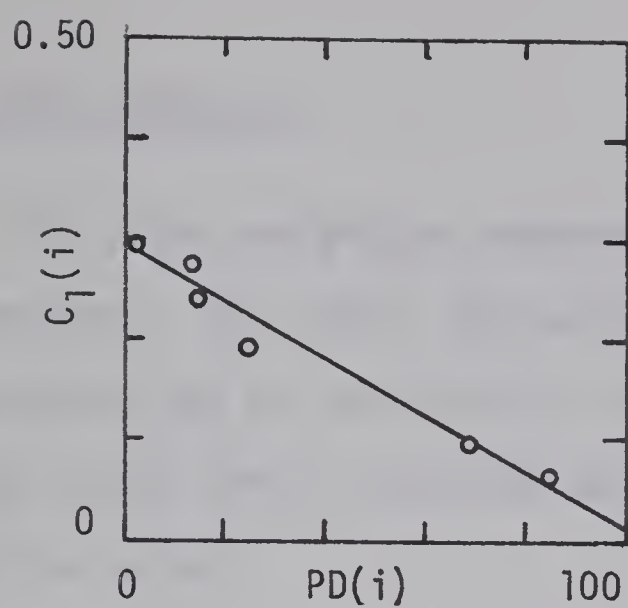


Figure 4-2
Fourier Coefficients $C_j(i)$ as Functions of $PD(i)$

4-4-3 Random Component

The actual weight per household curve ($w(i,t)$) is composed of three components: the trend, the periodic and a random component. The random component may be calculated by taking the relative deviations between the actual $nw^*(i,t)$ and the $nw(i,t)$ as given by the fitted short Fourier series.

If the following are defined:

$nw^*(i,t)$ = actual normalized weight for route i .

$nw(i,t)$ = value of normalized weight given by Fourier series.

Then the relative deviations ($u_w(i,t)$) are defined as such:

$$u_w(i,t) = \frac{[nw(i,t) - nw^*(i,t)]}{nw^*(i,t)} \quad (4-24)$$

The relative, rather than the absolute deviation is used in this case as it was observed that the deviations are larger when the actual quantities are larger. Or in other words, the random fluctuations are directly dependent on the magnitude of the variable. The relative deviation thus allows the comparison of the random components on an equal basis.

The relative deviations for two of the sample routes are given in Figure 4-3 and this distribution may be considered a normal one for the modeling purpose. Thus the variable $u_w(t)$ is considered to be constant for all routes, and to be normally distributed with mean 0, and standard deviation 0.14.

$$u_w(t) = \text{Norm}(0.0, 0.14) \quad (4-25)$$

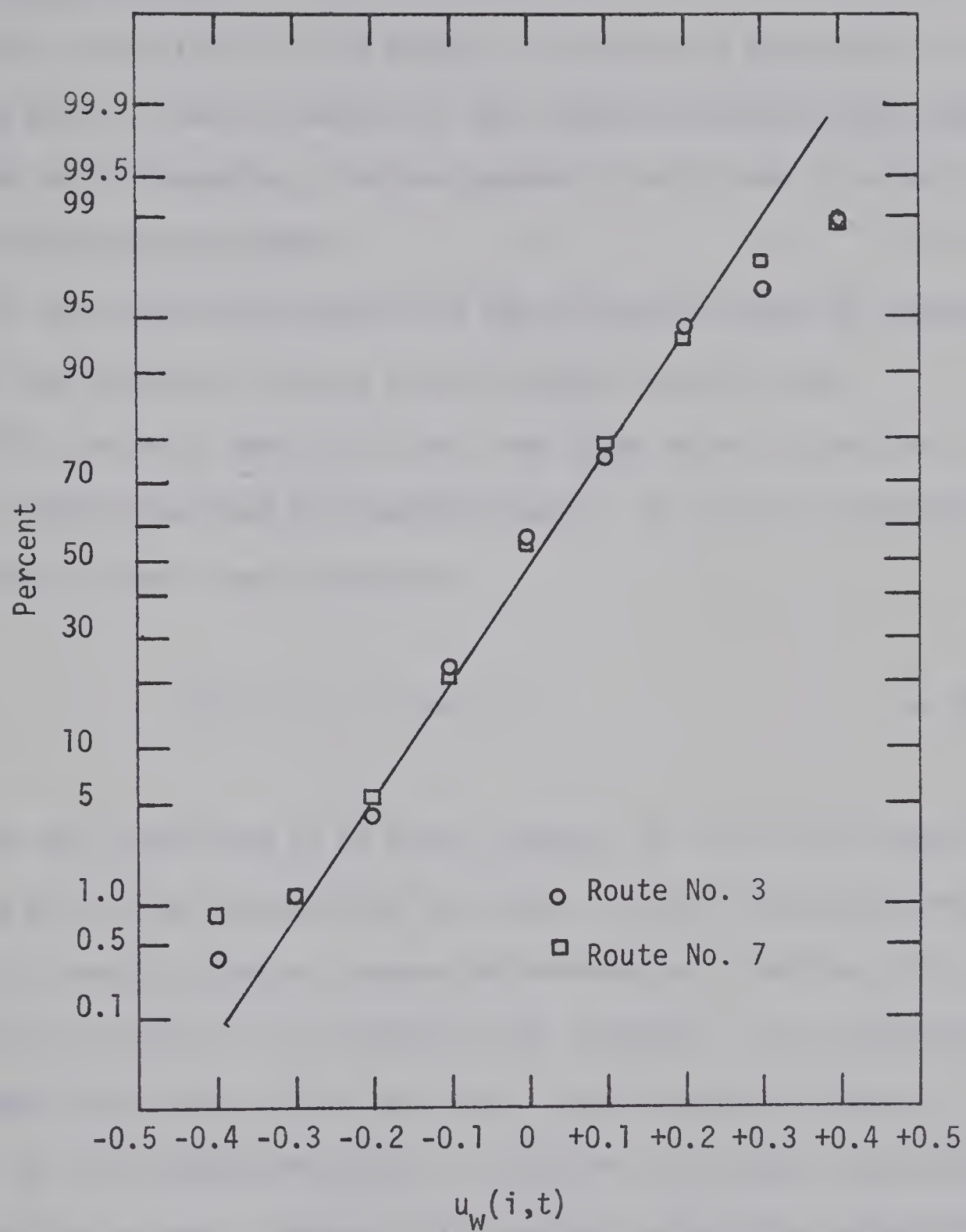


Figure 4-3

Normal Probability Distribution of $u_w(i,t)$

4-5 Analysis of Density Data

4-5-1 Density of Refuse

The collection of solid wastes is carried out essentially on a unit load basis. Thus the weight of the refuse collected weekly must be expressed as representing a certain number of unit loads in order to calculate resource requirements.

To this effect the density of the collected refuse as expressed in 1000 lb. per standard load has been extracted from the data.

This variable density (d) has been found to be a function of the actual weight generated per household-week. In fact the relationship is a first order linear one where:

$$d(i,t) = a + b w^*(i,t) \quad (4-26)$$

The function has been found to be quite constant for all of the sample routes, and also to be constant for each year over the five year period.

In a way this was an unexpected observation: that the refuse becomes heavier as more of it is generated per household. The difference between summer and winter refuse densities, when the summer refuse is denser due to the increase proportion of heavier yard wastes, may explain this observation in part. However this does not explain the proportional density increase from one winter season to the next. One possibility is that as more wastes are produced, the collectors would tend to pack more into a load in an attempt to hold the number of loads constant. Whatever the reason, complete analysis of the refuse composition would have been required to determine the true causes of this relationship.

Whatever the reason, this was an observable fact and provides an easy modeling function to relate the number of loads to weight generation.

The constants of equation (4-26) were derived by least squares for the data from the sample routes, and are given in Table 4-4. As well the actual data and fitted line is shown for the routes in Appendix C.

The modeling function for the density of the collected refuse is therefore given by:

$$d(i,t) = 1.41 + 0.0257 w(i,t) \quad (4-26A)$$

TABLE 4-4
CALCULATED LEAST SQUARES COEFFICIENTS
FOR THE VARIABLE $d(i,t)$

Fitted to the equation: $d(i,t) = a + bw(i,t)$

Route	a	b	Correlation Coefficient	Relative Std. Deviation
1	1.19	0.0229	0.850	11.3%
3	1.53	0.0224	0.809	9.4%
7	1.29	0.0323	0.820	10.4%
30	1.21	0.0317	0.701	8.4%
31	1.65	0.0178	0.504	8.8%
42	1.49	0.0258	0.725	9.6%
47	1.55	0.0268	0.728	10.8%
Average	1.41	0.0257		9.85%

4-5-2 Random Component

As may be seen in Appendix C, (Figures C-1-4, to C-7-4), the actual density values are distributed about the least squares line in a random fashion. Thus a random component may be added to the density modeling function.

This random component is taken to be defined by the relative deviation, where:

$d^*(i,t)$ = actual density value.

$d(i,t)$ = theoretical density from least squares line.

and

$$u_d(i,t) = \frac{[d(i,t) - d^*(i,t)]}{d^*(i,t)} \quad (4-27)$$

The random variable $u_d(i,t)$ is thus defined as:

$$u_d(i,t) = \text{Norm}(0.0, 0.0985) \quad (4-28)$$

4-6 Analysis of Collection Time Data

4-6-1 Travelling Time

The total collection time required for each load of refuse is composed of two parts: the time required to actually travel within the source area and collect the refuse, and the time required to transport this load from the source to the sink, dump the load and return.

Data was available giving the actual distances and times required for a round trip from each route to the different disposal areas. The time requirements included time for dumping plus the crew rest period.

The obvious generalizing correlation variable in this case is what is called the L-metric length. This length is defined as the length of an L-shaped path from one point to another along the natural street orientations in a city. The justification for this variable is that in going from one point to another, a vehicle will not take a direct path, but follow the streets and thus the shortest path is equivalent to a simple L-shaped route.

Thus the L-metric length was calculated from a city street map from the center of each route to the different disposal points. The city was divided by an X-Y coordinate system scaled in miles with the origin located at the incinerator. Each route and disposal point was thus defined as an X-Y point in these coordinates.

Equations of the form:

$$TTIME(i,j) = a + b D(i,j) \quad (4-29)$$

$$Dist(i,j) = a + b D(i,j) \quad (4-30)$$

where

$$D(i,j) = |x(i) - x(j)| + |y(i) - y(j)| \quad (4-31)$$

were calculated for routes leading to each disposal point. The constants obtained by the least squares fits are given in Table 4-5.

It may be seen that this correlation holds well. In the case of the distance correlation, there is a non-zero intercept which can be explained by a certain doubling back of the vehicles which would occur as their travelling is restricted to the major streets.

Similarly the time intercept is greater for the incinerator disposal point by about 5 minutes indicating that more time is required at this point for dumping, weighing being also included.

The modeling functions in this case are therefore:

$$TTIME(i,j) = WTIME(j) + 4.947 D(i,j) \quad (4-32)$$

and

$$WTIME(j) = 25.82 \quad \text{for the incinerator} \quad (4-33)$$

$$WTIME(j) = 20.32 \quad \text{for the dumps} \quad (4-34)$$

TABLE 4-5
LEAST SQUARES COEFFICIENTS OF TRAVEL TIMES
AND TRUE DISTANCE CORRELATION EQUATIONS

A - For the equation: $TTIME(i,j) = a + bD(i,j)$

Trip	a	b	Correlation Coefficient	Relative Std. Dev.
S.S. to S.S. Dump	18.225	5.184	0.913	6.5%
S.S. to Incinerator	26.550	4.406	0.952	6.0%
N.S. to Incinerator	25.097	5.361	0.954	6.1%
N.S. to Bev. Dump	21.670	4.650	0.939	6.6%
N.S. to Transfer Sta.	21.070	5.134	0.940	4.9%

B - For the equation: $Dist(i,j) = a + bD(i,j)$

Trip	a	b	Correlation Coefficient	Relative Std. Dev.
S.S. to S.S. Dump	0.839	0.877	0.908	10.1%
S.S. to Incinerator	0.517	0.988	0.975	12.6%
N.S. to Incinerator	1.181	0.941	0.893	17.5%
N.S. to Bev. Dump	0.655	0.891	0.982	8.0%
N.S. to Transfer Sta.	0.421	0.843	0.950	9.6%

4-6-2 Collection Time

Data giving the times required to collect a load for all routes was also available. An attempt to correlate this variable with the population density factor was unsuccessful. This variable is thus dependent upon other factors which were not available such as curb or alley collection, closeness of stops, etc.

For this variable therefore, the collection times will be used as exists without the benefit of a generalization function.

CHAPTER V

THE MODEL

5-1 Mathematical Formulation of the Model

The model is intended to be a representation of the city of Edmonton refuse collection system. The model is a dynamic one operating in time, and thus gives the state of the system at a given time. This state is defined by the model output or response variables. These response variables are:

Quantity variables: $W(i,t)$ and $L(i,t)$

Assignment variables: $A(i,j,t)$

Total cost variable: $TOTCO(t)$

- (a) Quantity variables: At a given time t , (or for a given week in time), the state of the collection system in terms of quantity of refuse to be collected is defined by the two vectors $W(i,t)$ and $L(i,t)$ which give the total weight of refuse to be collected in each of the n routes ($i = 1, n$) and the total number of standard loads this represents.
- (b) Assignment variables: For this time t , the assignment variable $A(i,j,t)$ gives the number of standard loads from the route i which are collected according to the collection alternative j ($j = 1, m$). The values of $A(i,j,t)$ are chosen by an optimizing procedure such that the total collection cost is minimized. The values of $A(i,j,t)$ may be:

$$A(i,j,t) = 0 \quad \text{if no loads from route } i \text{ are collected according to alternative } j. \quad (5-1)$$

$$A(i,j,t) > 0 \quad \text{if all or part of the loads are collected according to alternative } j. \quad (5-2)$$

and

$$\sum_{j=1}^m A(i,j,t) = L(i,t) \quad (5-3)$$

- (c) Total cost variable: For a given week, the total cost of the refuse collection is given by the sum of the costs for each route. The cost for each route is the product of the number of loads collected according to the alternative j , $A(i,j,t)$ and the unit cost per load for that alternative, $C(i,j)$.

The response variables are functions of the input variables and parameters of the model. That is the values of the input will determine the responses. For the variables involved the inter-relationships between them may be stated as follows:

$$W(i,t) = f[i,t,PD(i),NOHOU(i), u_w(t)] \quad (5-4)$$

$$d(i,t) = f[i,t,w(i,t),u_d(t)] \quad (5-5)$$

$$L(i,t) = f[i,t,W(i,t), d(i,t)] \quad (5-6)$$

$$C(i,j) = f[TTIME(i,j), CTIME(i,j),FCTIM(j),FLOAD(j),RCOST(j),TCOST(j)] \quad (5-7)$$

$$A(i,j,t) = f[L(i,t),BCAPY(j,t),C(i,j)] \quad (5-8)$$

$$\text{TOTCO}(t) = f(A(i,j,t), C(i,j)) \quad (5-9)$$

The explicit modeling functions given in sequential order as they are used in the model, are as follows:

Quantity Generator:

$$t = (\text{NYEAR} - 1966)52 + \text{IWEEK} \quad (5-10)$$

$$\bar{w}(t) = 45.06 + 0.051t \quad (5-11)$$

$$u_w(t) = \left[\sum_{k=1}^{12} R_k - 6.0 \right] \times 0.14 \quad (5-12)$$

$$c_1(i) = 0.2885 - 0.002710\text{PD}(i) \quad (5-13)$$

$$c_2(i) = 0.0923 - 0.000669\text{PD}(i) \quad (5-14)$$

$$c_3(i) = 0.1104 - 0.000801\text{PD}(i) \quad (5-15)$$

$$c_5(i) = 0.0384 - 0.000244\text{PD}(i) \quad (5-16)$$

$$\begin{aligned} \text{nw}(i,t) = & 1.00 + c_1(i)\cos\left(\frac{2\pi}{52} \text{IWEEK} - 3.522\right) \\ & + c_2(i)\cos\left(\frac{4\pi}{52} \text{IWEEK} - 4.410\right) \\ & + c_3(i)\cos\left(\frac{6\pi}{52} \text{IWEEK} - 1.072\right) \\ & + c_5(i)\cos\left(\frac{10\pi}{52} \text{IWEEK} - 0.445\right) \end{aligned} \quad (5-17)$$

$$w(i,t) = [1.0 + u_w(t)][nw(i,t)\bar{w}(t)] \quad (5-18)$$

$$u_d(i,t) = \left[\sum_{k=1}^{12} R_k - 6.0 \right] \times 0.0985 \quad (5-19)$$

$$d(i,t) = [1.0 + u_d(i,t)][1.41 + 0.0257w(i,t)] \quad (5-20)$$

$$W(i,t) = w(i,t)NOHOU(i) \quad (5-21)$$

$$L(i,t) = \frac{W(i,t)}{d(i,t)} \quad (5-22)$$

Cost Generator:

$$D(i,j) = |x(i) - x(j)| + |y(i) - y(j)| \quad (5-23)$$

$$TTIME(i,j) = WTIME(j) + 4.947D(i,j) \quad (5-24)$$

$$COLTI(i,j) = CTIME(i)FCTIM(j) \quad (5-25)$$

$$TOTTI(i,j) = TTIME(i,j) + COLTI(i,j) \quad (5-26)$$

$$TOSTT(i,j) = \frac{TOTTI(i,j)}{FLOAD(j)} \quad (5-27)$$

$$C(i,j) = RCOST(j)TOSTT(i,j) + TCOST(j) \quad (5-28)$$

Optimizer:

$A(i,j,t)$ and $TOTCO(t)$ are given by:

$$\text{Minimize } TOTCO(t) = \sum_{j=1}^m \sum_{i=1}^n A(i,j,t)C(i,j) \quad (5-29)$$

Subject to:

$$\sum_{j=1}^m A(i,j,t) = L(i,t) \quad \text{for } i=1,n \quad (5-30)$$

$$\sum_{i=1}^n A(i,j,t) \leq BCAPY(j) \quad \text{for } j=1,m \quad (5-31)$$

$$L(i,t) \text{ and } BCAPY(j) \geq 0$$

Input Variables and Parameters:

- NYEAR - Year of interest for simulation
- IWEEK - Week in year, first week is 1, last is 52.
- PD(i) - Population density parameter of route i.
- NOHOU(i) - Number of household units in route i.
- x(i),y(i) - Location of route i.
- x(j),y(j) - Location of sink j.
- WTIME(j) - Waiting time at sink j for load dumping.
- CTIME(i) - Time to collect a standard load for route i.
- FCTIM(j) - Time factor to correct for collection time under alternative j.
- FLOAD(j) - Ratio of load capacity of alternative j to standard load.

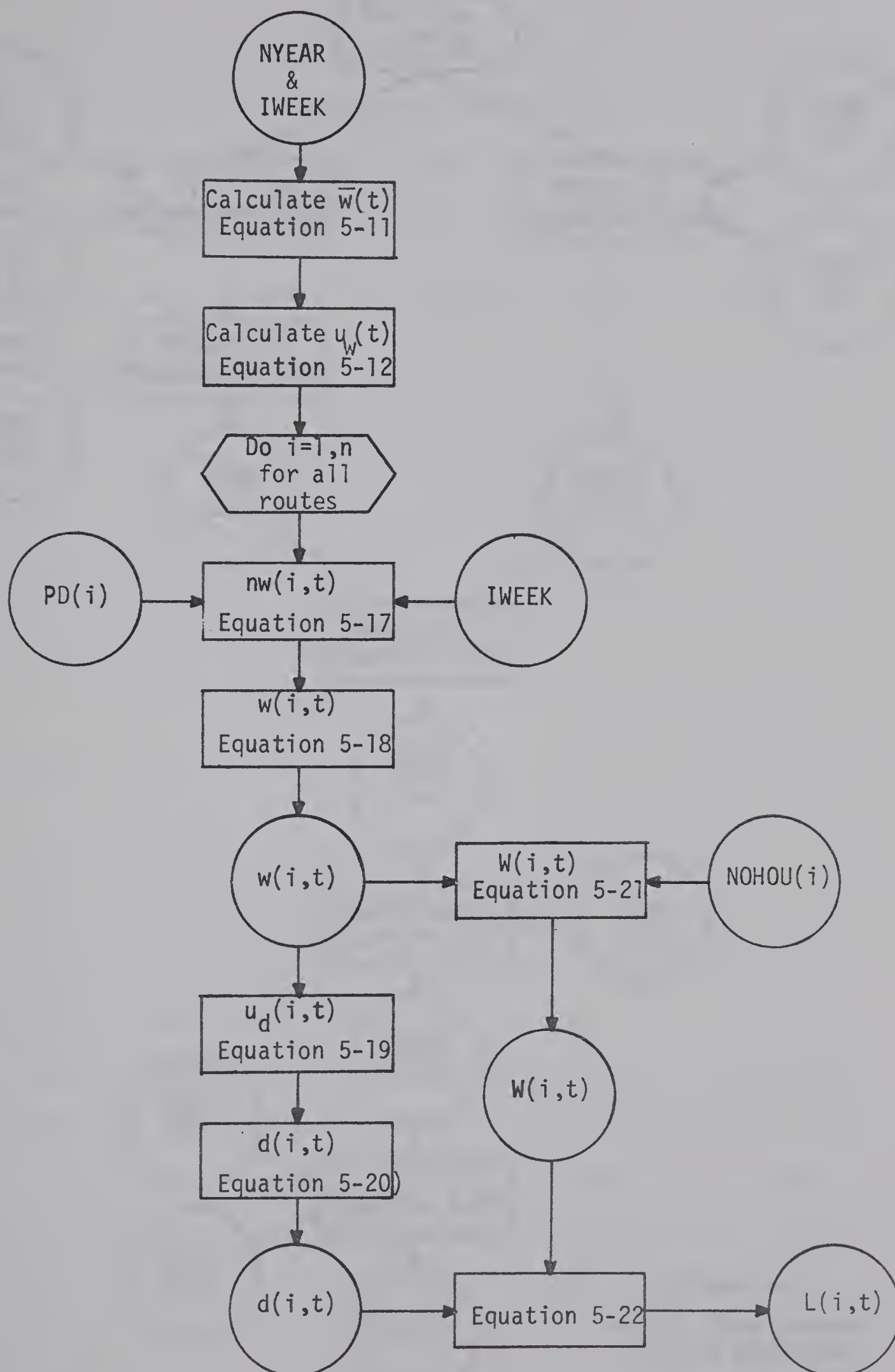


Figure 5-1
Logical Flow Diagram of Quantity Generator

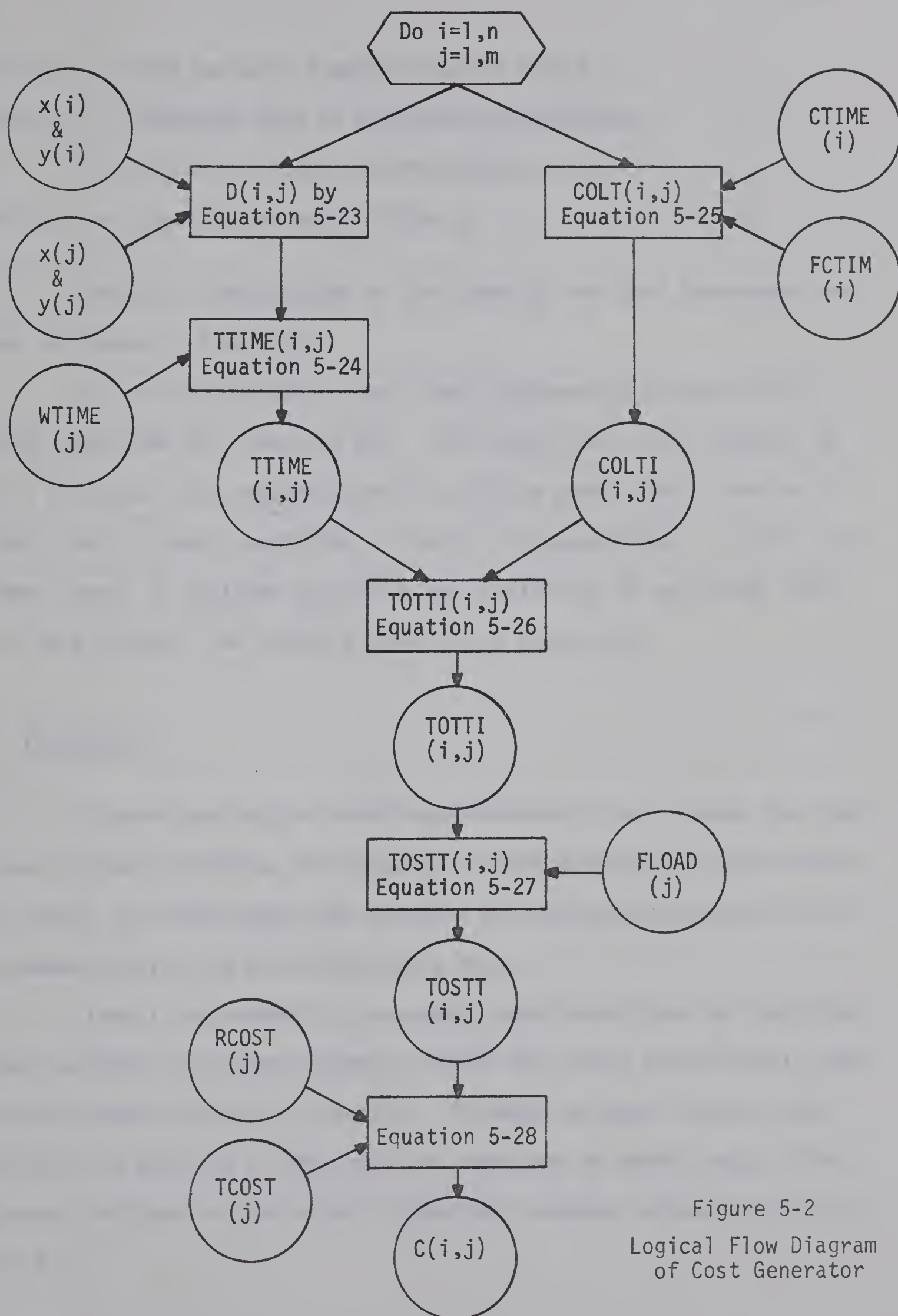


Figure 5-2
Logical Flow Diagram
of Cost Generator

- RCOST(j) - Cost per unit time for crew to sink j.
- TCOST(j) - Treatment cost at sink per standard load.
- R_k - Series of random numbers between 0 and 1.
- BCAPY(j) - Capacity per week of sink j.

Detailed flow diagrams of the Quantity and Cost Generators are given in Figures 5-1 and 5-2.

As for the Optimizer, the linear programming transportation problem algorithm has been used (6). This algorithm is the simplest to use in this case, the problem being to allocate paths from n sources to m sinks, with integer quantities in need of transportation. In this case a dummy source is included to handle the possibility of unlimited sinks, or to have greater sink capacity than source quantities.

5-2 Validation

A model can only be considered representative if under the input of known given conditions, the response is that which would occur in the real world. For this model the responses are the quantity vectors, the assignment matrix, and the total weekly cost.

Thus if this model is run under actual conditions as they have already existed, the above responses should not differ significantly from those that were obtained in practice. In order to check this out, the conditions as existing in 1966 and 1970 were used as model inputs. The responses obtained and the actual historical response values are given in Table 5-1.

As to the quantity responses it is seen that the total yearly weights and loads are higher for the model, by respectively -2.0% and 3.6% in 1966 and 6.5% and 6.7% in 1970. Sample time curves for the two years are shown in Figures 5-3 and 5-4. It may be noted that these curves do indeed follow the real curves, resulting in essentially the same cyclical behavior.

The model assignments are optimized, thus they are presumably better than the real world assignments. However in this case the problem deals with only three well spaced sinks, one of which is capacity limited. Thus the assignments can be fairly well determined by simple inspection. This being the case, little difference was noted between the model assignments and those in actual practice.

The total cost, as expressed in total crew and vehicle hours is again higher for the model resulting from the greater quantities produced by the model. However the increase is not quite as great for the model, reflecting the use of the optimizing technique.

Overall the model responses as compared to the actual historical data for the years 1966 and 1970 is of the order of 5% too high. This can be considered to be good agreement between the model and the real world system, and thus indicates that the model is indeed a valid representation of the real system.

TABLE 5-1

COMPARISON OF MODEL RESULTS WITH ACTUAL VALUES

Year - 1970	Model	Actual	Error
Total Weight (tons)	141,300	132,680	6.5%
Total Std. Loads	97,685	91,524	6.7%
Average Density (1000 lb./ld.)	2.89	2.89	0.0%
Total Time Required (hours)	155,185	149,790	3.6%
Tons per Man-Year*	950	940	1.1%
Total Weight to Incinerator	59,100	NA	
Total to South-side Dump	29,300	NA	
Total to Beverly Dump	52,900	NA	
Year - 1966	Model	Actual	Error
Total Weight (tons)	100,200	102,023	-2.0%
Total Std. Loads	77,594	74,882	3.6%
Average Density	2.58	2.72	-5.1%
Total Time Required (hours)	121,614	NA	-
Tons per Man-Year*	860	885	-2.8%
Total Weight to Incinerator	59,200	NA	
Total to South-side Dump	14,800	NA	
Total to Beverly Dump	26,200	NA	

* One Man-Year = (40 x 52) = 2080 hours.

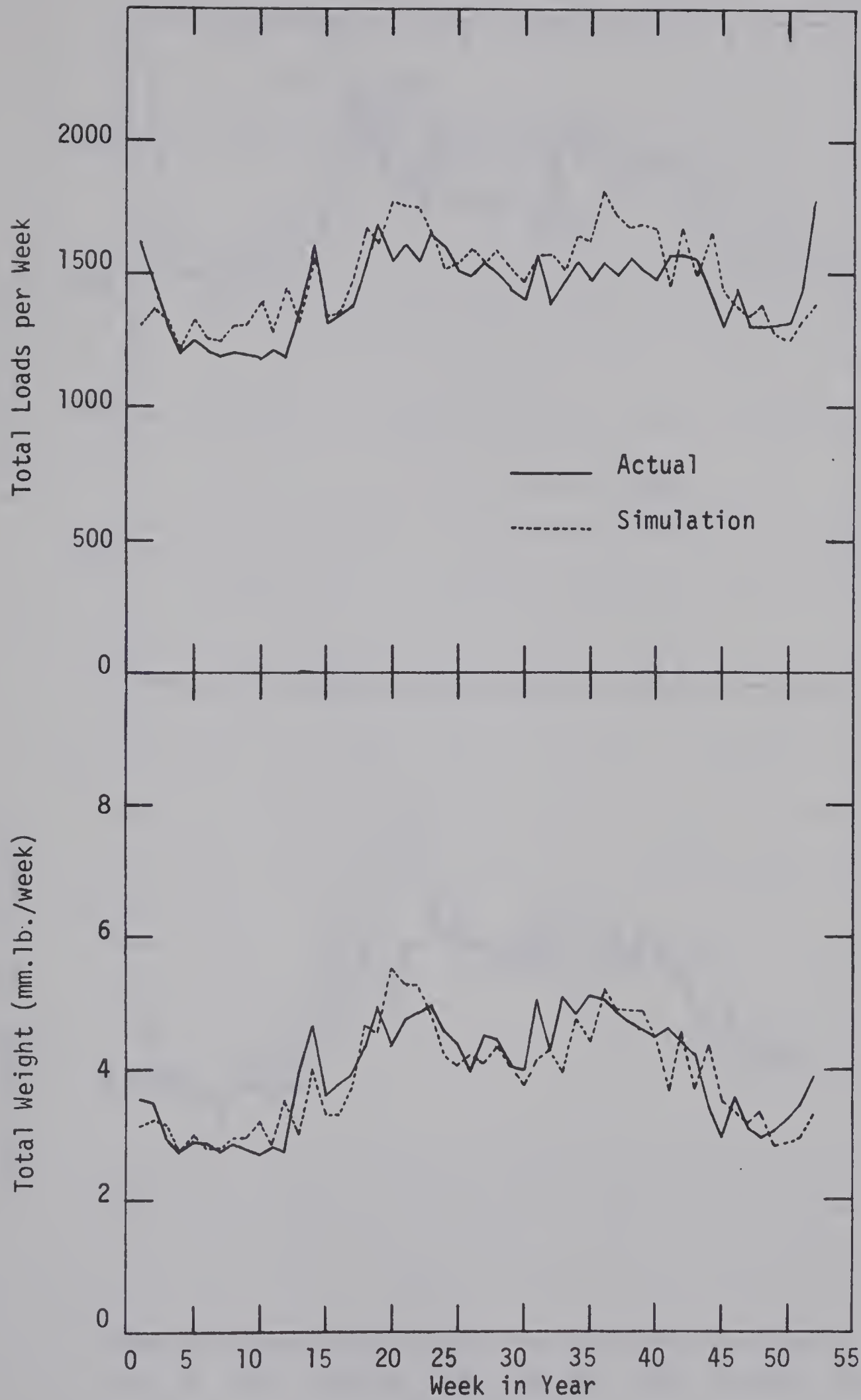


Figure 5-3
Comparison of Actual and Simulated
Refuse Quantities for 1966

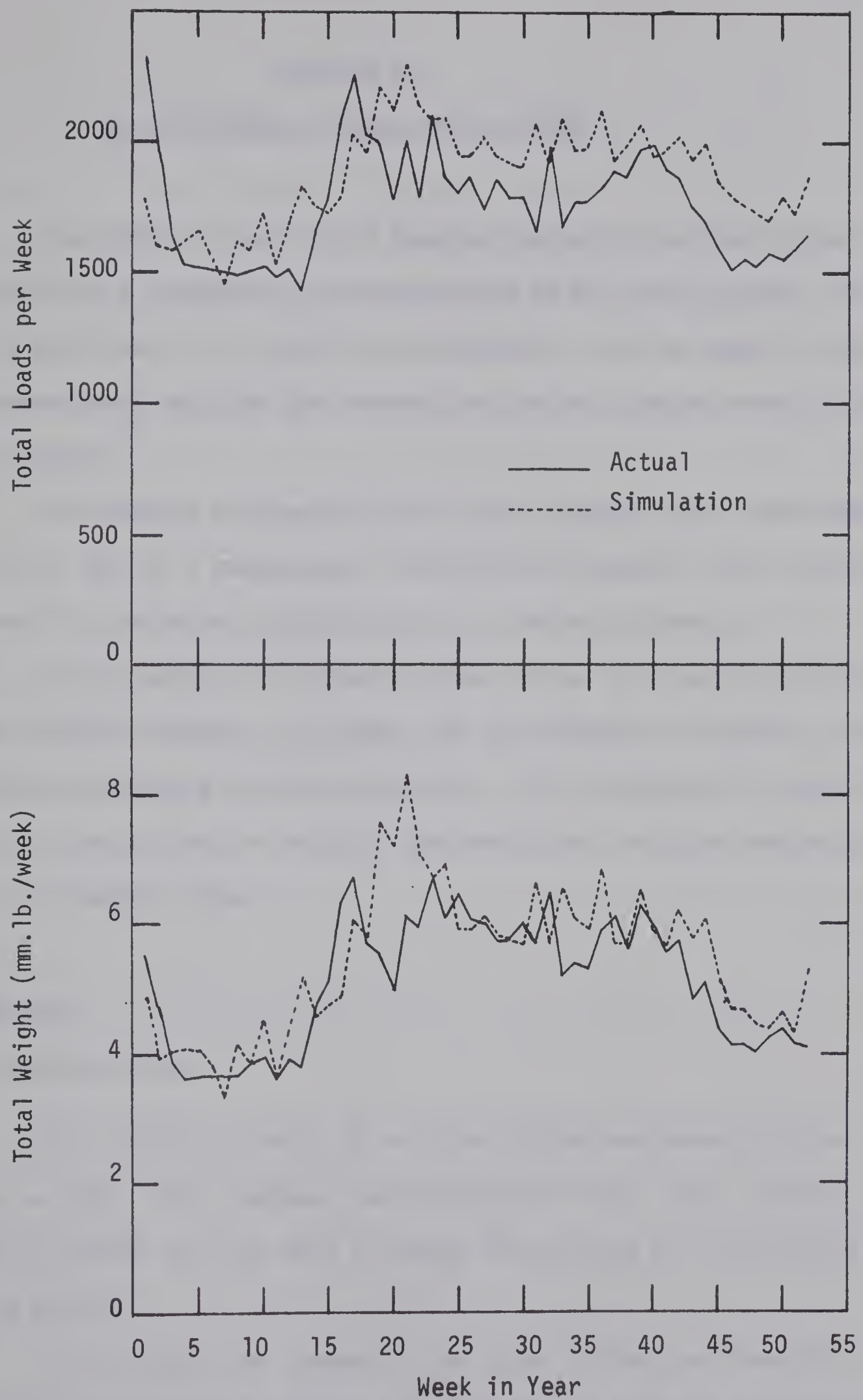


Figure 5-4

Comparison of Actual and Simulated
Refuse Quantities for 1970

CHAPTER VI

ILLUSTRATIONS OF MODEL APPLICATIONS

The model of the City of Edmonton refuse collection system is intended to be a mathematical representation of the actual system. As such its usefulness is to permit experimentation with the model in order to determine what would be the response of the real system under various sets of inputs.

The current problem with which the city Sanitation Department is faced is that of a change-over from multiple disposal sites relatively near the city limits to a single site at a greater distance.

Thus a series of simulation experimental runs were carried out using an IBM/360 computer. In these runs the effects of locating a number of different dumping sites were considered. This analysis is a sensitivity analysis of the collection costs as they would vary with the number and location of dumping sites.

6-1 Results

6-1-1 Series A Runs

For the first series of runs the system considered was that as existed in 1970. This includes the collection of the refuse from the whole city except for that part of Jasper Place which was serviced on a contract basis.

In this case the changes in the total collection times (the time required to collect and transport a load of refuse from the collection routes to the dumping site whether a dump, transfer station, etc.) were

examined as they related to the number and location of various sites throughout the city. The costs of operating these dumping sites, trans-shipment from these sites, or any other factors were not considered. Secondly all of the sites were considered to be of unlimited capacity: that is they could handle all of the refuse transported to them.

As there are political limitations to the location of transfer stations, they may not normally be located in residential areas, the possible site locations were limited to sites within industrial areas.

The results of this series A runs are given in Table 6-1 & 2 and are shown in Figure 6-1.

In Figure 6-1 the breakdown of the total collection time is also shown. This reveals that on the average 54.2 minutes are required to collect a standard load of refuse. This collection time only includes the time required to travel within the route, stopping at the individual collection spots and loading the refuse.

A further 20.3 minutes are taken up in turn-around time. This is a constant time taken up in the transportation of a load and includes various elements such as getting the vehicles unto the main arteries, delays in reaching and entering the dumping site, waiting at the site, dumping etc. These delays would seem to be a constant regardless of the distance to the disposal site and may be explained in part by the fact that generally more time efficient itineraries may be used for longer trips. This time constant is the constant found in equation (4-33, 4-34).

Finally the third component of the total collection time is the part representing actual travelling time, the time the vehicle actually spends moving normally from the source area to the disposal area. As seen in Figure 6-1 this is the only part of the total collection time that varies with the number and location of dumping sites.

This travelling time component varies considerably with the number and location of sites, though the actual variation cannot be predicted theoretically as this system is interacting and non-uniform. However some general observations may be made regarding the variations of the travel times. Firstly it is noted that for a given number of disposal sites, certain combinations of locations are more efficient than others. This is readily comprehensible considering that a site serving a specified area should be centrally located. Also in a case of multiple sites, balanced sites serving approximately equal areas would likewise be more efficient.

A second observation, not so readily seen, is that the increase in efficiency obtained by adding extra sites is not constant but decreases with the number of sites, even if they are optimally located.

These observations may be expressed quantitatively for very idealized conditions as shown in Appendix A. It is shown that the effect of misplacing a site within a given servicing area may cause a travel time increase of up to twice that of the optimal site location. Secondly the total travel times vary inversely as the square root of the number of sites.

TABLE 6-1

LOCATION OF POSSIBLE TRANSFER STATION SITES

Site No.

- | | |
|----|--|
| 1 | New Clover Bar Dump - Assumed to be 12 min. round trip from Beverly Dump site. |
| 2 | West-end Transfer Station |
| 3 | Incinerator Location |
| 4 | Near 66 Ave. and 103 Str. |
| 5 | Near 45 Ave. and 103 Str. |
| 6 | Near 124 Ave. and 70 Str. |
| 7 | Near 142 Ave. and 107 Str. |
| 8 | Near 124 Ave. and 107 Str. |
| 9 | Near 82 Ave. and 58 Str. |
| 10 | Beverly Dump |
| 11 | South-side Dump |
| 12 | 3 Ton Vehicle to New Clover Bar Dump |
| 13 | 3 Ton Vehicle to West-end Station |
| 14 | 3 Ton Vehicle to Station near 45 Ave. and 103 Str. |

Note: Sites No. 1 to 11 involve the use of the standard 18 cu.yd. collection vehicle only.

Sites No. 12 to 14 assume the use of a collection vehicle of twice the standard vehicle capacity.

TABLE 6-2
SERIES A - 1970

Run	Number of Sites	Site Identification	Average Time Required Per Load (Min.)
5	3	2, 4, 6	86.4
6	3	2, 5, 6	87.8
7	3	1, 2, 4	91.3
8	3	1, 2, 3	93.2
9	3	2, 7, 9	90.1
10	4	2, 4, 6, 9	85.3
11	4	2, 3, 5, 6	85.6
12	4	2, 4, 7, 10	87.0
13	4	2, 3, 10, 11	90.0
14	4	1, 2, 5, 7	88.5
15	5	2, 4, 6, 7, 9	84.6
16	5	2, 3, 5, 6, 7	86.1
17	5	2, 3, 7, 10, 11	88.2
18	5	2, 3, 5, 6, 9	85.6
20	2	2, 9	92.9
21	2	4, 7	89.4
22	2	7, 11	96.5
23	2	1, 2	99.4
24	2	2, 3	92.3
25	1	3	93.6
26	1	2	101.0
27	1	8	96.3
28	1	11	110.0
29	1	1	120.2
30	62	Average Collection & Turn-around time only	74.5
31	62	Average Collection Time only	54.2

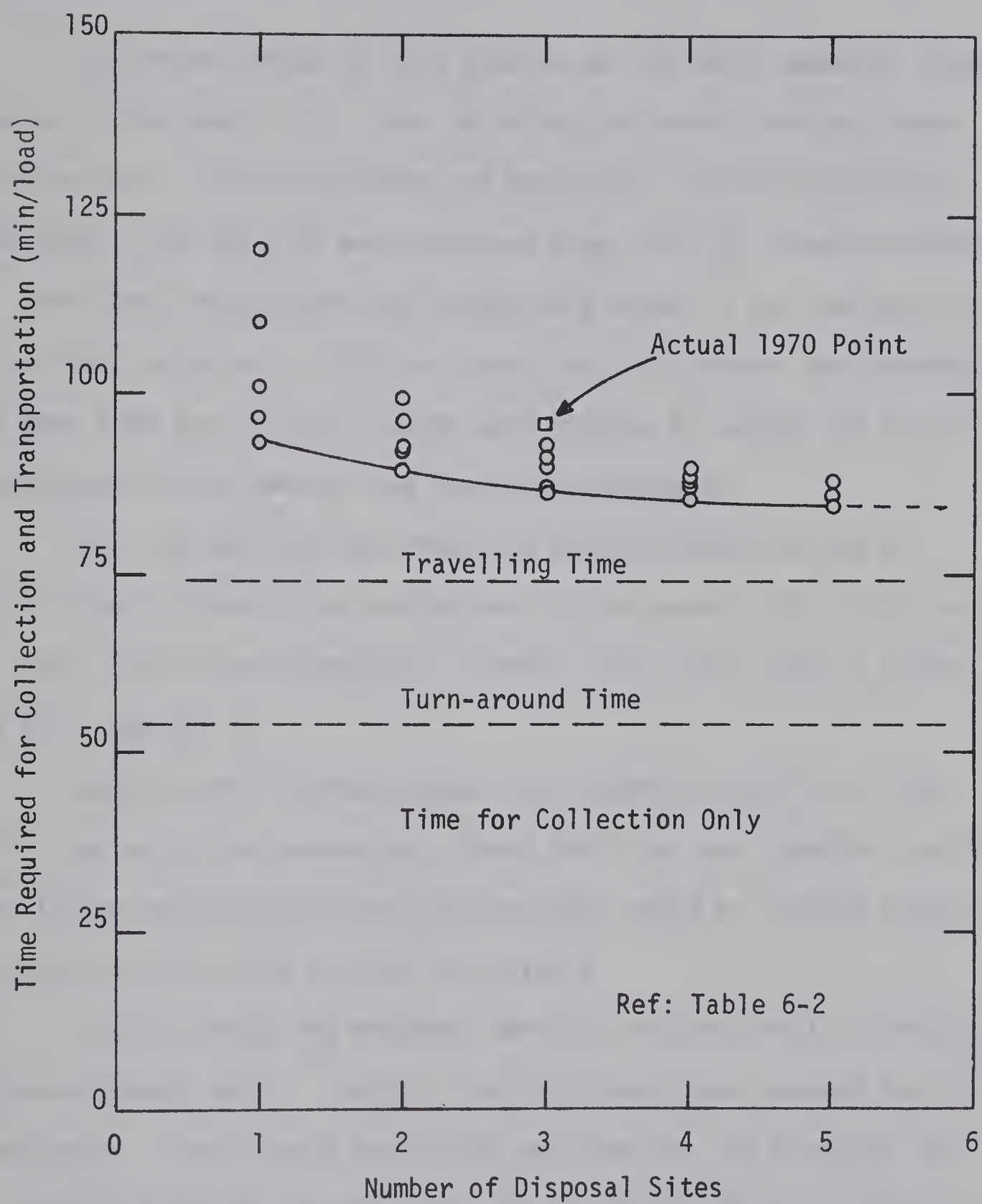


Figure 6-1
Total Collection Time as a
Function of Disposal Site Number

6-1-2 Series B Runs

The second series of runs considered the total domestic refuse generation in the whole city, thus including the parts serviced under private contract. Also population and population density projections for the years 1976 and 1981 were obtained from the city planning department. From these projections new routes were added in the new developments to those existing in 1970 on a basis of 3.96 persons per household. At the same time the existing routes were revised by adding the population increases in the form of new apartment households.

Thus the existing and projected household maps served as inputs to study disposal site variations for the years 1970, 1976, and 1981. The location and parameters of these routes are given in Tables D-1 to D-3, Appendix D.

Secondly the disposal system was assumed to consist of one landfill site only, the developing Clover Bar site, and transfer stations similar to the existing West-end station which could be located within only certain areas of the city as in series A.

In this series the response variable was the total collection and trans-shipment costs. For this the 1970 rates were assumed for all runs and years. These costs are \$12.00 per hour for the standard 18 cu.yd. vehicle plus the two man crew, and \$26.00 per 40 cu.yd. load of ground refuse from the transfer station to the dump. The 40 cu.yd. load of shredded refuse was assumed to represent 7 standard non-shredded loads or a density increase factor of 3.15 resulting from grinding. However the costs of operating and amortizing these stations are not included.

It is assumed that the cost of transportation of the ground refuse would not differ greatly from one location to another, being mainly a fixed charge. Thus the unit cost of \$26.00 has been assumed a constant for all locations. These costs thus represent the total costs involved in collecting and transporting the refuse from the generation areas to the stations, and from there to the ultimate disposal area.

The results of the series B runs are given in Table 6-3 & 4 and Figure 6-2. The total costs are plotted as a function of $(m)^{-1/2}$, where m is the number of dumping sites, according to the correlation function given in Appendix A. It is seen that the costs do follow this dependence on m as expected.

The costs are given in terms of 1970 dollars and may be updated to 1976 and 1981 through multiplication by whatever the cost index for that year may be as compared to 1970. This however assumes that the ratio of the collection crew costs to the bulk transportation costs of the ground refuse remains approximately the same as in 1970.

It is seen that the location of the sites for a given number of sites has a bearing on the total costs as well as the total number of sites. Secondly the slope of the curves is seen to increase in 1976 and 1981 as the total load on the collection system increases. Thus the pay-off to be expected by adding extra sites increases as the wastes load and servicing area increases. In fact the 1981 slope is double the 1970 slope.

TABLE 6-3
 SERIES B - 1970 & 1981

Run	Number of Sites	Total Cost ('000 1970 Dollars)	Corresponding 1976 Run
57 - 1970	1	2,609	48
87	1	2,536	84
86	1	2,415	85
56	2	2,356	73
54	3	2,271	70
55	3	2,232	94
51A	3	2,227	42
53	4	2,248	63
52	4	2,218	69
50	4	2,217	67
51	4	2,207	68
49	5	2,194	75
39 - 1981	1	4,627	48
89	1	4,591	84
88	1	4,352	85
38	2	4,245	73
36	3	4,024	70
33A	3	4,013	42
37	3	4,000	94
32	4	3,997	67
33	4	3,997	68
35	4	3,963	63
34	4	3,955	69
31	5	3,900	75

TABLE 6-4
SERIES B - 1976

Run	Number of Sites	1	2	3	4	5	6	7	Total Cost (1970 - '000 Dollars)
48	1	100							3,570
84	1		100						3,501
85	1			100					3,325
90	2		67		33				3,297
73	2	46	54						3,266
91	2		57.5		42.5				3,260
92	2				58			42	3,245
74	2		33						3,210
93	2			67	53		47		3,197
95	3	15	49				36		3,216
79	3		35			33		32	3,183
77	3		25.5		42.5			32	3,146
76	3		26					23	3,138
71	3	20.5	33	51					3,118
70	3	35.5	36	46.5		28.5			3,115
96	3		29.5	41			29.5		3,109
78	3					27	42		3,104
94	3	30	34		36				3,093
42	3		29		35		36		3,083
65	4	10	30	41			19		3,083
64	4	13.5	31			27	28.5		3,074
82	4		24	37.5		16		22.5	3,073
67	4	11	26	44				19	3,073
63	4	25	28			28		19	3,070
68	4	11.5	29		35				3,055
69	4	19.5	25.5		36		24.5		3,048
83	4		27.5			16	29.5	19	3,045
75	5	11.5	24	27		16		19	3,008
58	5	10	27.5	27		16	19.5		3,019
59	6	10	24	27		16.5	10.5	12	2,991

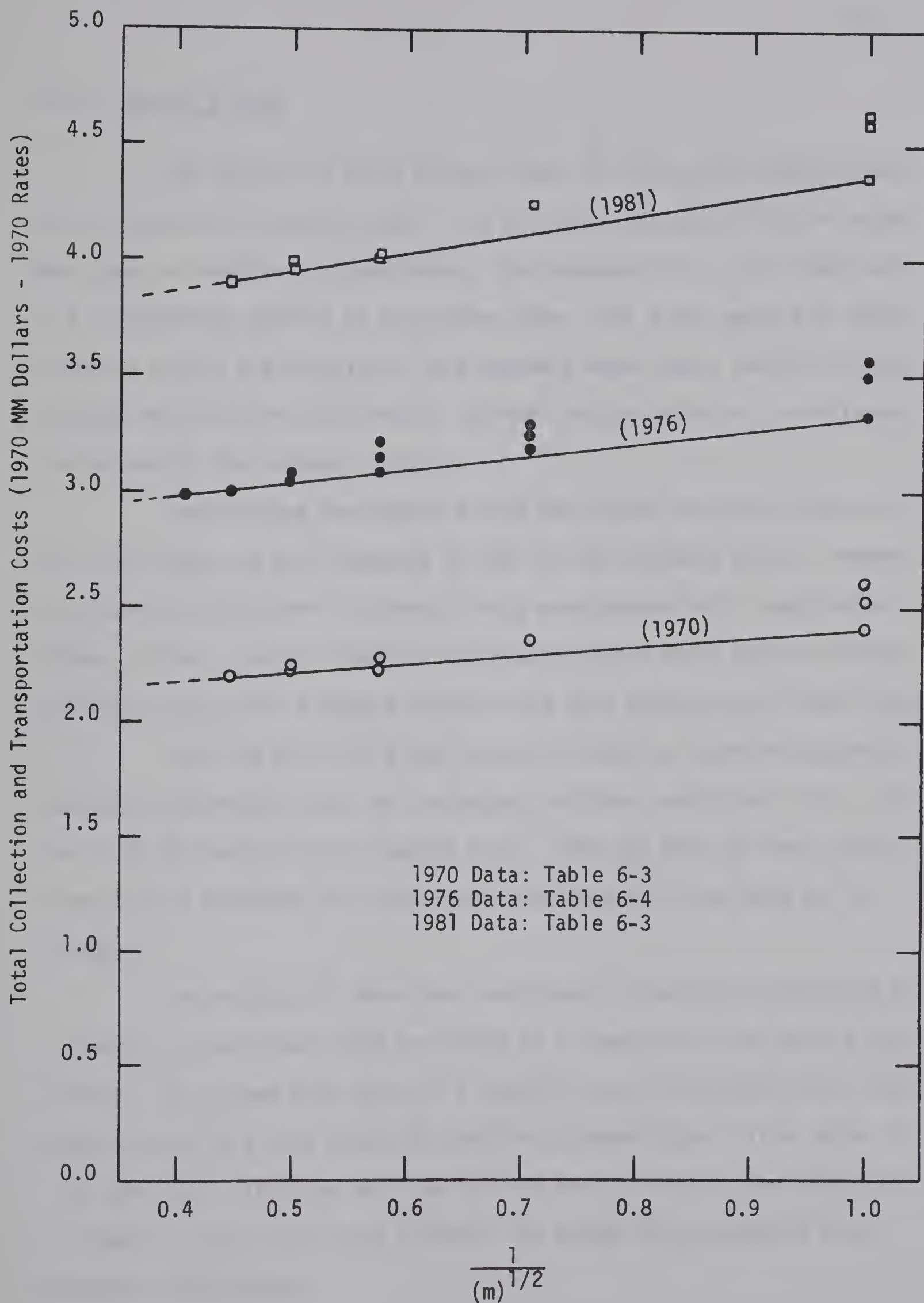


Figure 6-2

Total Collection Costs as a Function of Number of Sites (m)

6-1-3 Series C Runs

The effects of using various types of collection vehicles may also be examined using the model. In this case the possibility of using two types of vehicles is considered: the standard 18 cu. yd. truck and a 3 ton capacity vehicle of the packer type. The 3 ton vehicle is approximately double the capacity of the standard open truck, and thus it was assumed that the time required to collect one load with this vehicle was twice that of the standard vehicle.

Time savings are obtained with the higher capacity truck as it must only make one trip compared to two for the standard truck. However this vehicle costs more to operate being more mechanically complicated. There is thus a certain travelling distance beyond which these are more efficient, while the standard vehicles are less expensive for short hauls.

Thus the mix of the two types of trucks was examined assuming the hourly operating costs of the packer unit and crew to be 1.15, 1.20, and 1.25 the costs of the standard unit. This was done for two cases of dumping site locations for 1976, using the same unit cost data as in series B.

The results of these runs are given in Table 6-5 and Figure 6-3. In this case the total costs are shown as a function of the vehicle cost ratios. It is seen that there is a certain cost ratio beyond which the packer trucks are more expensive than the standard type. This ratio is 1.29 for the 4 site case and 1.32 for the two site case. The higher cut-off ratio in the 2 site case reflects the longer hauls required over certain of the routes.

TABLE 6-5
SERIES C - 1976

Run	Number of Options	Cost Factor of 3-Ton Vehicle	1	2	5	7	12	13	14	Total Cost (1970 - '000 Dollars)
63	4	Not Used	25	28	28	19	-	-	-	3.070
60	6	1.15	-	0	0	3	47	25.5	24.5	2.824
61	6	1.20	-	6	0	8	42	19.5	24.5	2.926
62	6	1.25	-	18.5	20.5	11	41	5.5	3.5	3.005
73	2	Not Used	41	54	-	-	-	-	-	3.266
80	3	1.15	-	0	-	-	68	32	-	2.885
81	3	1.20	-	6	-	-	64	30	-	3.001
72	3	1.25	-	20.5	-	-	63	16.5	-	3.106

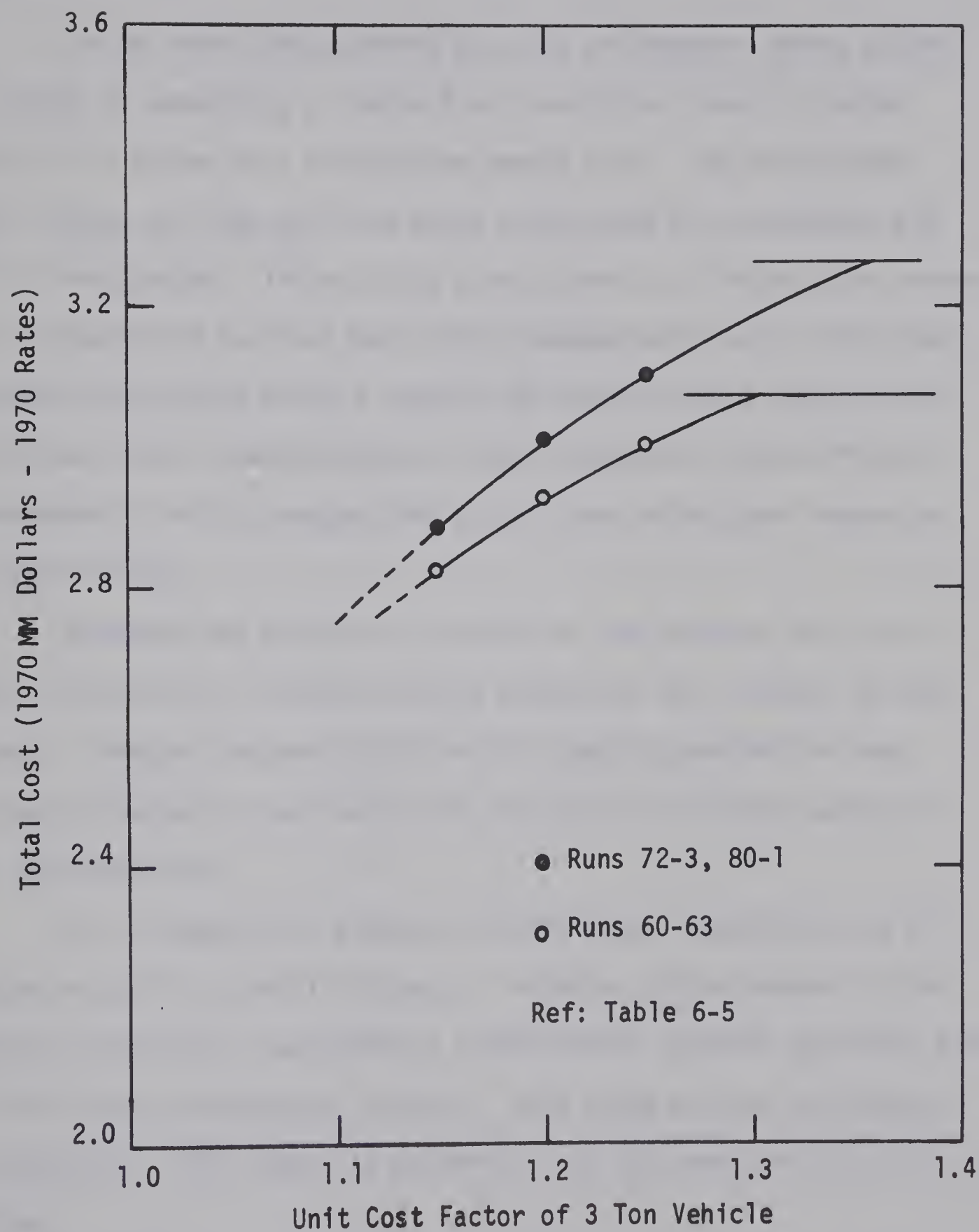


Figure 6-3

1976 Data - Total Collection Costs with Mixed Fleet
of 1.5 and 3 Ton Capacity Vehicles

6-2 Discussion

As has been stated before the City of Edmonton refuse collection system is undergoing a change from a multiple closely situated disposal site system to a single more remote site. The implications of this change are such that the whole system must be re-examined and possibly reorganized. The multiple site system is a flexible one, essentially fragmentized and thus more easily managed with less interactions. The remote site system being a centralized one, has more interactions, and thus many more possibilities and their respective trade-offs must be considered. In this respect the city is now in the same league as the larger cities.

Whatever the outcome or solution to the problem, the cost of refuse collection will increase simply because of the increase in haul distances. However the best solution will seek to provide the most satisfactory system at the least cost, and with this enters many political considerations.

As an example the present thinking tends towards the use of shredded refuse for landfill disposal. Grinding refuse however is an expensive proposition, but produces a much better landfill operation with less health and environmental hazards. What value must be assigned to these benefits? This cannot be answered; thus the need for political decisions.

In this respect we therefore assume that a political decision has been taken, namely to operate the landfills on totally ground domestic refuse.

In such a case, the system requires grinding plants and the next question is how many and where shall they be located. This is the question which we attempted to answer by the preceding computer simulation trials.

6-2-1 Number of Stations

From Figure 6-2 it is seen that the decrease in total collection and transportation costs decrease with the addition of extra stations, but that this decrease is less and less as the number of stations increases. Thus the optimal decrease obtained in adding one more station to existing ones is given in the table below for the years under consideration.

Number of Existing Stations	Optimal Pay-off Obtained by Adding One More Station (1970 Dollars)		
	1970	1976	1981
1	117,000	170,000	235,000
2	51,000	74,000	102,000
3	31,000	45,000	62,000
4	22,000	31,000	43,000

The above table thus indicates that when adding new stations the capital and operating costs of a new station must be balanced against the savings obtained in transportation costs.

As an example, if the yearly operating and amortizing costs of an extra transfer station is 100,000 (1970 \$) the above table indicates that savings could be achieved by operating two stations in 1970 and three in 1981.

The above analysis however only considers that the stations be optimally located in every case. The effect of sub-optimal location would result in pay-offs different from those shown above and would have to be considered separately case by case.

6-2-2 Location of Stations

The effect of location choice upon the total collection costs was examined more fully in the series of runs for the year 1976. These runs were carried out considering the fact that a transfer station existed in the West-end of a capacity of 800 tons per 40 hours with provisions for doubling of this capacity. Starting with this existing location, other stations were added at various locations. The new Clover Bar dump was also considered as a location since there are no trans-shipment charges at this point, and also this location allows the grinding of refuse other than only domestic. Table 6-4 contains the summarized results of these trials.

It is seen that the best locations for a set of three stations would be that of Run 42. This pattern is the more symmetric one under the constraint that the locations be within industrial areas. In this case the city is divided into three servicing areas, with one station serving the South-side, and the other two the North side. Another possibility on the lines of this pattern is that of Run 94 where the North-east sector is serviced by a station at the dump site. This case eliminates the trans-shipment costs from the North-east sector, though it must assume the costs of longer hauls.

It would seem that the best location for a South-side transfer station would be in the area near 103 Str. and 66 Ave. This area is quite centrally located to serve this sector. A second South-side possibility is that near 103 Str. and 45 Ave. This alternative site however incurs costs increase of the order of \$20,000 per year.

A North-side location to complement the West-end station would be one near 124 Ave. and 70 Str., provided the dump is not used as a station site. If the new dump is used, the dump site itself becomes the site servicing the North-east sector. The present incinerator location is an acceptable site only if two or four stations are proposed. In the case of three stations it is not the best location.

6-2-3 General Considerations

Another possible solution which has been explored only slightly is the use of a combined fleet of vehicles -- the standard open trucks being used for the short hauls, with the packer-type units used on the longer hauls. In this case there would be the possibility of operating the collection system with a minimum number of transfer stations. An example of this case is the one given in Figure 6-3 where this combination of vehicles is used with the West-end station and the new dump as disposal sites. It is noted that at a cost factor of 1.25 for the 3 ton trucks, the total costs are about the same as for a three station system. To draw conclusions regarding this solution will however require much more accurate cost and performance data for the higher capacity units.

Finally any system design will have to take into account the large fluctuations which occur in the refuse production. The design will have to be able to cope with the peak weeks, and yet not cater overly to these conditions. One solution to peak conditions is to operate normally under 1-2 shifts and add an extra shift to handle the overload.

The projections of average, peak and low refuse production for the whole city for the years studied are given in Table 6-6 and Figure 6-4. It is seen that as the average weekly production increases, the fluctuations become much more serious.

In conclusion we have here only studied the travelling component of the total collection costs. From Figure 6-1 it is seen that this component is a small but important part of these costs. Any solution that can increase the efficiency of the actual collection component could yield larger benefits. Similarly the turn-around component may be examined with a view towards increased efficiency. Finally, an obvious solution, though in a different domain, is to decrease the total wastes generation. Although trite, it is a solution.

TABLE 6-6
PROJECTION OF TOTAL DOMESTIC REFUSE PRODUCTION
IN THE CITY OF EDMONTON

	1970	1976	1981
Yearly Total (Tons)	153,900	236,000	336,200
Weekly Average (MM. lb./wk.)	5.92	9.17	12.92
Average Winter (MM. lb./wk.)	4.30	7.00	10.00
Average Summer (MM. lb./wk.)	7.00	11.00	15.00
Peak Week (MM. lb./wk.)	8.43	13.30	18.16
Low Week (MM. lb./wk.)	3.96	6.13	8.66
Average Density (lb./18 cu. yd.)	2878	3253	3624
Total Number Standard Loads	106,945	145,097	185,545
Population	430,000	535,000	620,000

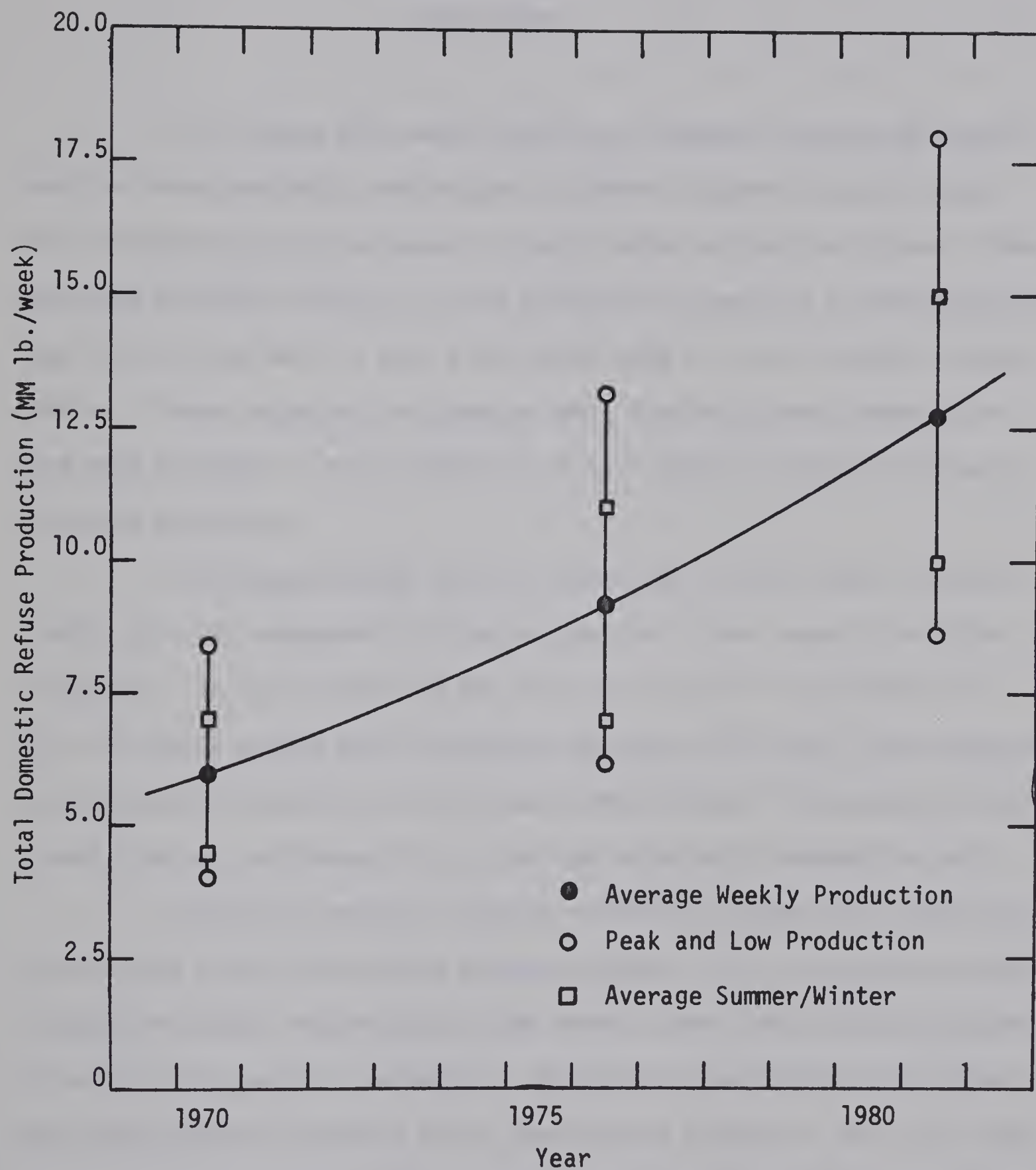


Figure 6-4
Projection of Total Domestic Refuse Generation
in the City of Edmonton

CHAPTER VII

CONCLUSIONS

The changes with which the City of Edmonton Sanitation Department is faced presently with regards to their ultimate disposal sites, will necessitate a reassessment of their refuse collection system. There are many possible solutions to the problem of organizing a collection system that will be able to work efficiently with this new ultimate disposal system. These solutions are complex ones, involving many interactions and many variables. It is difficult in such cases to evaluate the many possible solutions.

The computer model which is described in this thesis can be a useful tool for management for the evaluation of the range of possible solutions. In this respect it may be used to predict the behavior of the collection system both in time and in space. The small time required to simulate the system over a one year period (about 100 seconds of computer time per run) makes this a fast and relatively inexpensive tool.

The model simulates only the collection system, thus only one part of the total solid wastes disposal system. It can therefore provide simulation answers regarding only the effects upon the collection system of varying the decision variables. The decision variables of the model are the location of dumping sites, performance factors of the collection vehicles and unit costs. Illustrations have been shown of these applications.

The model has been shown to provide reliable predictions as to the effects of operating the collection system under multiple dumping site options. More important it has confirmed the theoretical observations that the decrease in transportation costs are less and less as the number of dumping sites increase. Similarly the model may be used to evaluate site combinations and find the better combinations for a given number of sites. In this respect the costs of certain political decisions may be assessed.

The model may also be used to evaluate the economics of introducing new types of collection equipment. An illustration of this application has been given. However reliable evaluations of such equipment would require accurate cost and performance data about it. Such data may be available from other users of this type of equipment, and actual extensive field trials.

As stated in the introduction, this model is a first level abstraction of the city's refuse collection system. A basic assumption in the evaluation of new and different alternatives is that this alternative may be or is in fact organized in the most efficient manner. Thus, the model assumes that the system operates without undue overtime costs, delays, failures, etc. The problem of vehicle routing, load equalization, scheduling are not handled by the model; in fact it assumes that this is done efficiently.

In summary a computer simulation model has been given that will evaluate an important part of the total solid wastes disposal system: the domestic refuse collection system. It is hoped that it will find use in providing better management of the disposal of our solid wastes.

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APPENDIX A

The following table shows the results of the survey of the medical profession in the United States, as conducted by the American Medical Association, in 1910. The table is divided into two parts, the first showing the results of the survey of the medical profession in the United States, and the second showing the results of the survey of the medical profession in the United States, as conducted by the American Medical Association, in 1910.

Year	Number of Physicians	Number of Surgeons	Number of Dentists	Number of Nurses
1910	100,000	50,000	20,000	10,000
1911	105,000	52,000	21,000	11,000
1912	110,000	54,000	22,000	12,000
1913	115,000	56,000	23,000	13,000
1914	120,000	58,000	24,000	14,000

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NOTES ON MATHEMATICAL METHODS USED

A-1 Equations for Curve Fitting

All of the generalizing equations used in this work are first order linear with the exception of the Fourier series. The standard least squares method has been used to calculate the constants of the generalizing equations (32).

$$\text{Where:} \quad y^* = a + bx \quad (\text{A-1})$$

$$a = \frac{\sum x_n^2 \sum y_n - \sum x_n y_n \sum x_n}{N \sum x_n^2 - (\sum x_n)^2} \quad (\text{A-2})$$

$$b = \frac{N \sum x_n y_n - \sum x_n \sum y_n}{N \sum x_n^2 - (\sum x_n)^2} \quad (\text{A-3})$$

The correlation coefficient was also calculated to indicate the goodness of fit, where $R = (-1, +1)$ suggests 100 percent correlation, and $R = 0$ suggest no correlation.

$$\text{Where:} \quad R = \frac{N \sum x_n y_n - \sum x_n \sum y_n}{\sqrt{[N \sum x_n^2 - (\sum x_n)^2][N \sum y_n^2 - (\sum y_n)^2]}} \quad (\text{A-4})$$

Finally the relative standard deviation was used to obtain an indication of the data spread. In all cases it was found that the actual data was distributed about the fitted lines in a sufficiently normal manner for it to be considered so distributed.

$$\text{Where } s^2 = \frac{1}{(N-1)} \sum \left(\frac{y_n}{y^*} - 1 \right)^2 \quad (\text{A-5})$$

As for fitting the Fourier series, the equations used to calculate these constants were given previously.

A-2 Comparison of Different Generalizing Equations

(a) Truncated Fourier Series.

The seasonal refuse generation variation is handled by means of a truncated 4 term Fourier Series in the model. Figure A-1-1 to A-1-4 show the effects of truncating the series at different points. In all of these cases the fourth and seventh terms are also omitted, as being negligible. It is noted that by retaining more terms the series approaches the true 26 term series. The 4 term series shown in Figure A-1-3, as that used in the model, is seen to retain the seasonal variations, with a minimum number of terms.

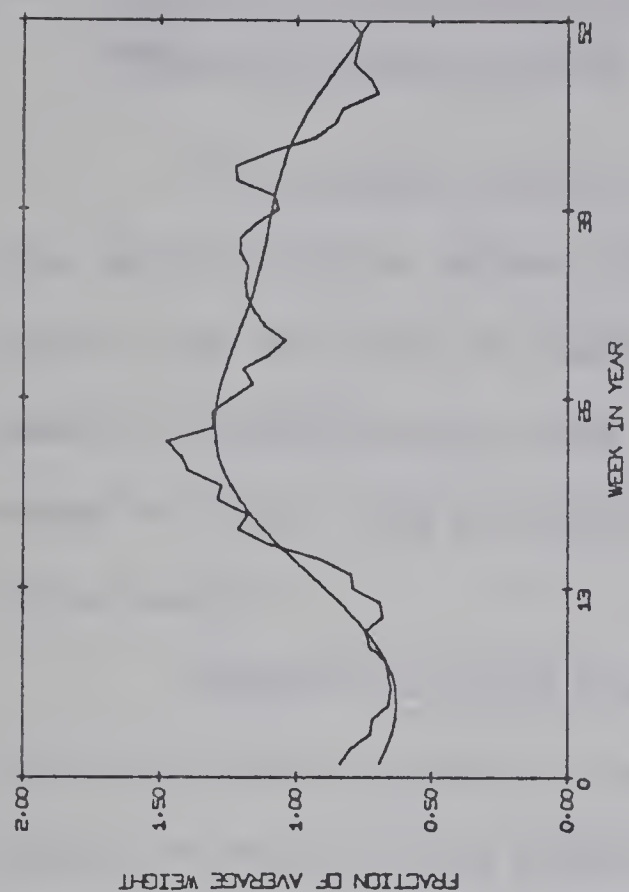


FIGURE A-1-2 ROUTE NO. 3 - 2 AND 26 TERM FOURIER SERIES

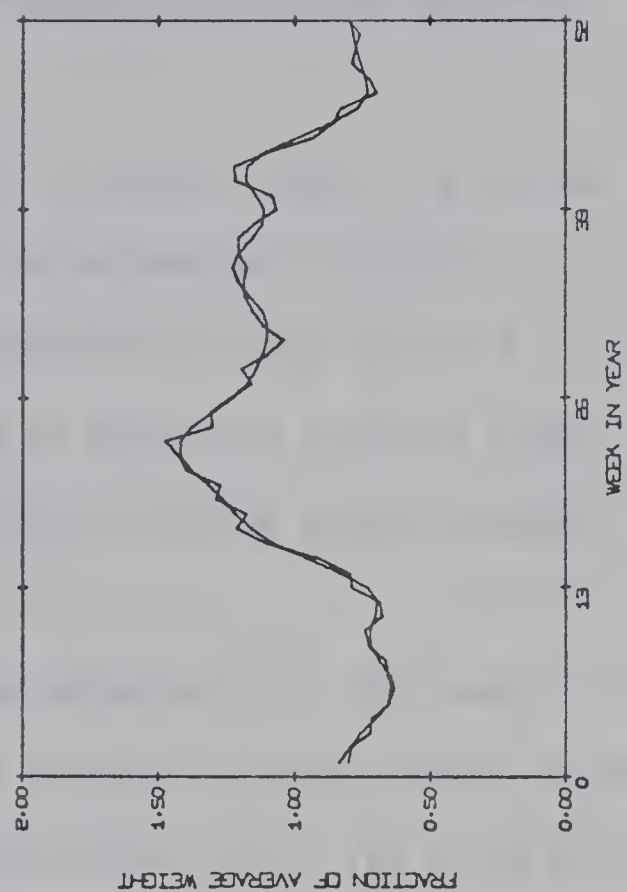


FIGURE A-1-4 ROUTE NO. 3 - 8 AND 26 TERM FOURIER SERIES

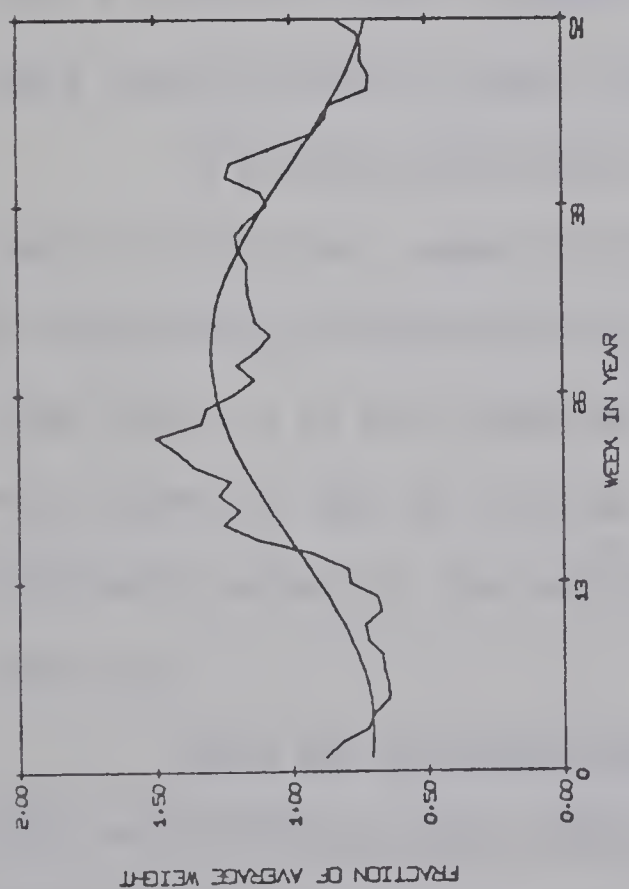


FIGURE A-1-1 ROUTE NO. 3 - 1 AND 26 TERM FOURIER SERIES

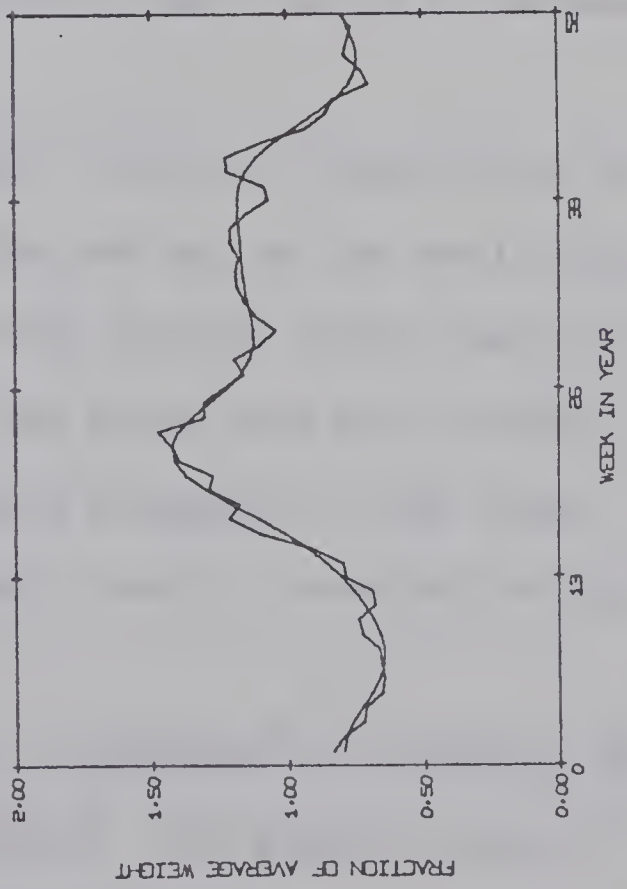


FIGURE A-1-3 ROUTE NO. 3 - 5 AND 26 TERM FOURIER SERIES

A-3 Note on the Relationship Between Transportation Costs and the Number of Disposal Points

The optimum location of central transfer sites in a collection service such as refuse collection (or warehouses, plants in a market area) has been the subject of considerable study (27). A number of algorithms have been developed to optimally locate a given number of sites, with the objective being to minimize total transportation costs.

However in actual practice, and especially in the case of a refuse collection system the question of optimum location cannot be asked. Because of political and esthetic considerations only a few sites are available and the problem is that of choosing the best locations. Thus with a relatively small number of alternatives each one may be evaluated and a decision made on these results.

A related problem to the optimal location of given sites, is that of the optimal number of sites. Also what may be the sensitivity of the minimum transportation cost objective function to the number of sites and also to site location. These two points have not received much attention, due to the wide variety and uniqueness of real cases also being subject to the physical geometry (usually irregular) of every real case.

Thus the following development is presented to illustrate the basic relationships which define this problem. The problem is one of simple geometry in which a very simplified and idealized case is considered: that of collecting a uniform product (refuse) over a regular area (a rectangle) with the product being uniformly distributed over the area.

Thus assume:

1. A rectangular uniform plane with constant refuse density (s) at all points in this plane.
2. A central disposal point in this plane of coordinates x_c and y_c to which the refuse is to be brought by a fleet of collection vehicles.
3. That the travelling distance from any point x_i and y_j in the plane to the central disposal point is given by the metropolitan metric length:

$$d_{ijc} = |x_i - x_c| + |y_j - y_c| \quad (A-6)$$

4. That the vehicles travel at constant speed (V mph) and that the cost per hour of the vehicle and crew is (k). Thus the cost of a return trip from a given point to the disposal area is:

$$c_{ij} = \frac{2k}{V} d_{ijc} \quad (A-7)$$

Consider:

The rectangular area being as shown in Figure A-2 with the central disposal point as located. This area may be divided into 4 rectangles as shown. Finally considering only one of these areas (A_2), the following may be derived:

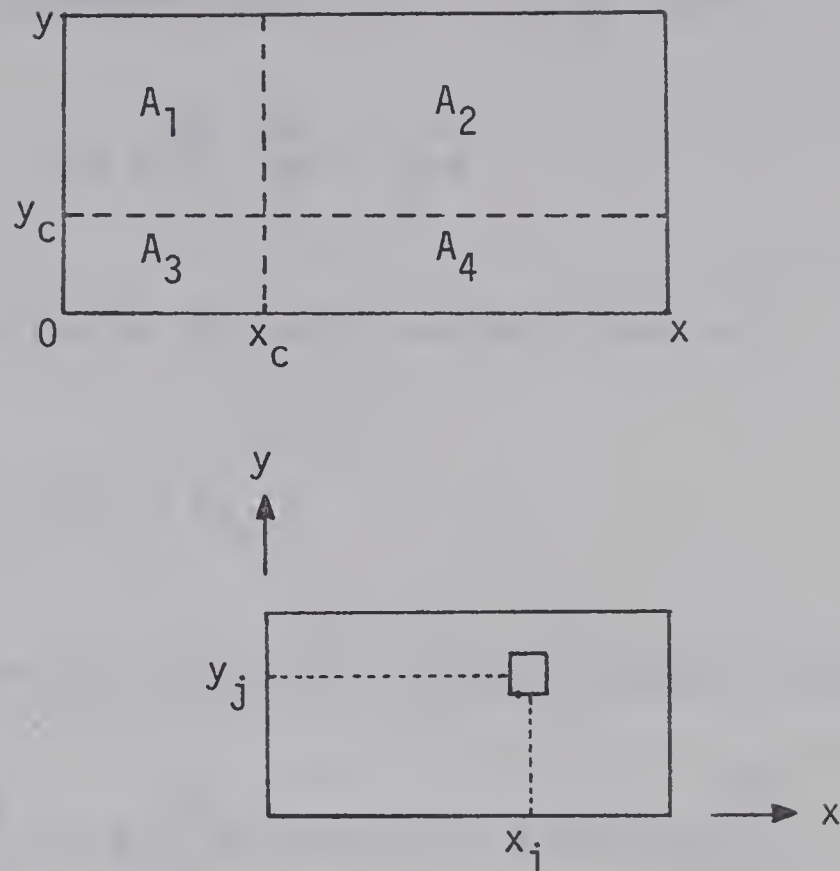


Figure A-2

1. For the small element of area shown ($\Delta x \Delta y$):

$$c_{ij} = s \frac{2k}{V} d_{ijc} \Delta x \Delta y \quad (\text{A-8})$$

$$= s \frac{2k}{V} (x_i + y_j) \Delta x \Delta y \quad (\text{A-9})$$

2. The total cost for the area A_2 is:

$$C = \lim_{\substack{n \rightarrow \infty \\ m \rightarrow \infty}} \sum_{i=1}^n \sum_{j=1}^m c_{ij} = \int \int \frac{s 2k}{V} (x + y) dx dy \quad (\text{A-10})$$

Integrating between the limits $x = 0$ to x and $y = 0$ to y :

$$C = s \frac{2k}{V} \left(\frac{x^2 y}{2} + \frac{xy^2}{2} \right) \quad (A-11)$$

3. For the whole rectangle the total cost will then be:

$$C_{TOT} = C_{A_1} + C_{A_2} + C_{A_3} + C_{A_4} \quad (A-12)$$

$$= \frac{sk}{V} \left[\left(x_c^2 (y - y_c) + x_c (y - y_c)^2 \right) + \left((x - x_c)^2 (y - y_c) + (x - x_c) (y - y_c)^2 \right) \right. \\ \left. + \left(x_c^2 y_c + x_c y_c^2 \right) + \left((x - x_c)^2 y_c + (x - x_c) y_c^2 \right) \right] \quad (A-13)$$

Which may be simplified by algebraic manipulation to:

$$C_{TOT} = \frac{1}{2} \frac{sk}{V} \left(xy(x+y) \right) \left[1 + \frac{y(x-2x_c)^2 + x(y-2y_c)^2}{xy(x+y)} \right] \quad (A-14)$$

Equation (A-14) thus gives the total cost of transportation within a rectangular area according to the assumptions stated. It is seen that the costs are proportional to the product of the area by the perimeter, the whole multiplied by a factor to take into account the off-center of the central point.

$$Z = \left[1 + \frac{y(x-2x_c)^2 + x(y-2y_c)^2}{xy(x+y)} \right] \quad (A-15)$$

- if the central point is located at the centroid, then $Z = 1$,
- if the central point is located within the area, but at the point furthest from the centroid ($x_c = 0, y_c = 0$), then $Z = 2$.

Thus the total transportation costs may be given by:

$$C_T = KA(x+y) Z \quad (A-16)$$

A similar theoretical relationship has been derived by Leamer (14), using the same assumptions with the exception that he used the closest distance rather than the metropolitan metric length used here. He derived a formula giving the best possible cost approached in the limit by dividing an area into a number (m) of regular hexagons. This formula is:

$$C(m) = \frac{\lambda}{m^{1/2}} \quad (A-17)$$

He gave illustrations by dividing a circle, square and triangle into a number of smaller areas and showed that the costs approach the above limiting formula.

The formula derived above (A-16) for the rectangle cannot be reduced explicitly to the form of equation (A-17). However if various cases of sub-dividing an area into different rectangles of nearly equal sizes the total cost may be calculated by:

$$C(m) = \sum_{j=1}^m C_j = K \sum_{j=1}^m A_j(x_j+y_j) Z_j \quad (A-18)$$

This has been done and is shown in Figure A-3 for three different rectangles (1 by 1, 1 by 2, and 1 by 4) of equal areas. In the case of the square, the divisions into 3, 5 and 6 parts are not optimal, but are quite close.

The costs, assuming $k = 1$ are given in Table A-1 along with the ratio of the costs to the standard cost chosen as that of the square. For all of these rectangles $Z = 1$ has been assumed.

CONCLUSIONS

The derivations given above are for a very idealized case whereas in practice, rarely are the areas of regular geometric shapes, or of uniform refuse distribution. However the derivation does point out the sensitivity of the transportation costs to the different factors, and it is this that we attempt to show.

1. Generally the total transportation costs vary inversely as to the square root of the number of central disposal facilities.
2. The shape of the physical area is of greater importance in the first sub-divisions, e.g. the pay-off in sub-dividing a square into two parts gives only a reduction of $1/4$ while the same gives a reduction of nearly $1/2$ for the 1×4 area. When a greater number of sub-divisions are made the benefits are about the same for all cases.
3. The location of a site has great importance as the number of sites increase as the incremental pay-off is less. Thus adding a badly located extra site may not achieve any cost savings at all.

The above conclusions do not and cannot state apriori what are the optimum conditions of a given system. Detailed analyses of all systems are still required. However they can caution one not to rely too heavily on common sense conclusions, such as one more transfer station (warehouse) must decrease costs, or that the pay-off is constant regardless of the number built, as that location is not altogether that important.

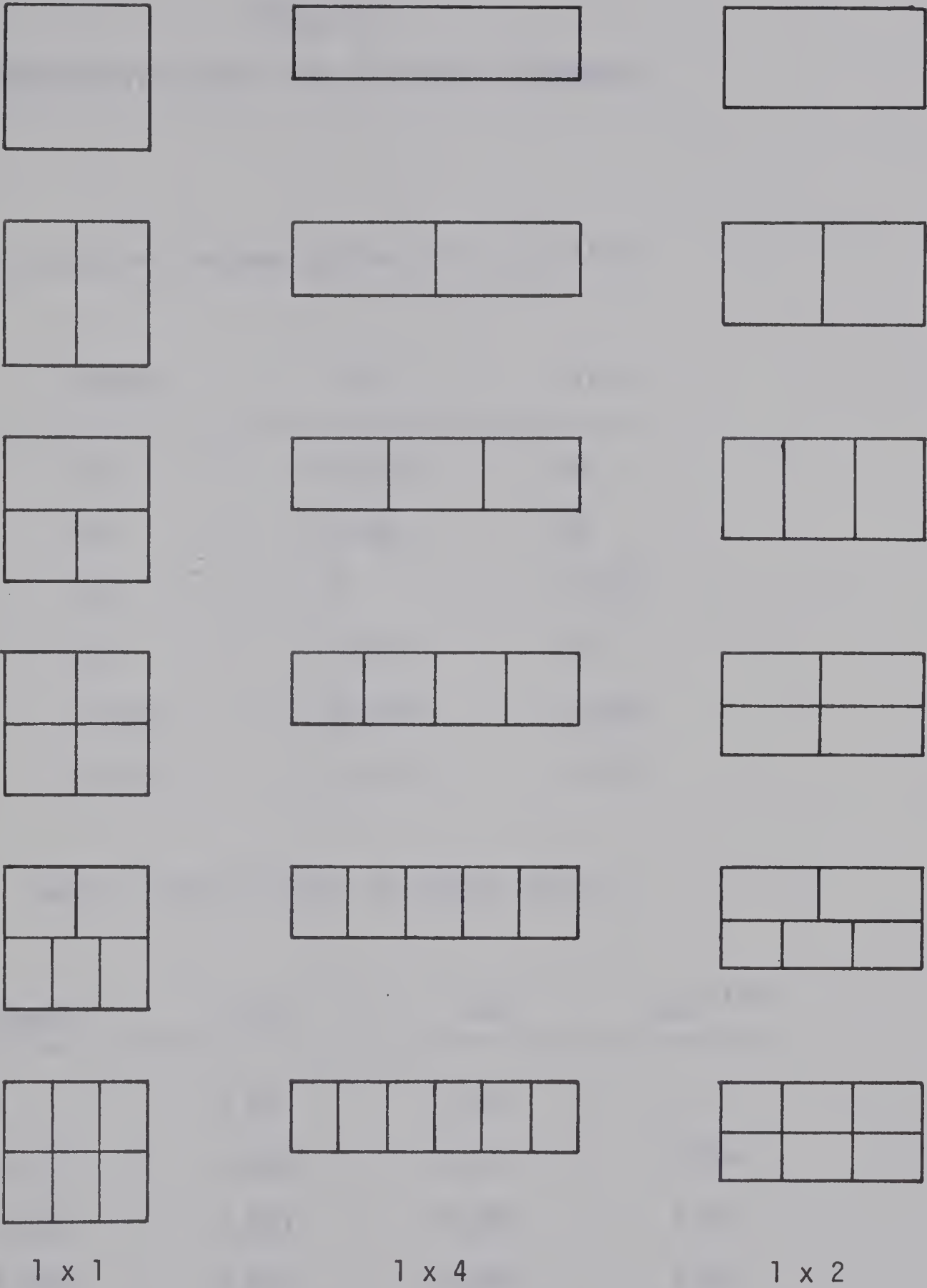


Figure A-3
Possible Rectangle Sub-divisions

TABLE A-1
TRANSPORTATION COST FOR DIFFERENT RECTANGLES

Example Costs of Transportation ($K=1$, $Z=1$, $A=4$)

m	Square	1x2	1x4
1	32	33.333	40
2	24	22.667	24
3	20	18	18.667
4	16	16.667	16
5	14.667	14.889	14.667
6	13.333	13.111	13.333

Ratio of Cost to that of Square for $m=1$

m	Square	1x2	1x4	$(m)^{-1/2}$
1	1	1.04	1.25	1
2	0.75	0.709	0.75	0.706
3	0.625	0.563	0.583	0.576
4	0.500	0.521	0.500	0.500
5	0.458	0.465	0.458	0.446
6	0.417	0.410	0.417	0.408

APPENDIX B

RAW DATA

The weight data obtained from the City of Edmonton Sanitation Department is given in the tables of this appendix. The data consisted of the total number of loads collected per week and the average weekly density calculated from the weighed loads as explained previously.

This data is reduced to the two basic variables: the weight per household-week of refuse generation, and the average density of this refuse in 1000 lb. per standard 18 cu. yd. load.

The above basic data is thus given for the sample routes covering the five year period over which the data was obtained.

TABLE B-1 WEIGHT AND DENSITY DATA FOR ALL CITY ROUTES

		** TOTAL WEIGHT (100,000 LB/WK) **					** DENSITY OF REFUSE (1000LB/LD)**						
** WEEK **	**	1966	1967	1968	1969	1970	**	1966	1967	1968	1969	1970	**
1		35.3	35.4	39.7	50.8	55.5		2.27	2.29	2.35	2.40	2.37	
2		30.5	35.0	38.2	44.5	47.1		2.24	2.36	2.38	2.51	2.40	
3		30.7	29.4	37.1	40.0	39.2		2.29	2.22	2.40	2.45	2.36	
4		30.0	27.0	35.1	39.6	36.5		2.32	2.19	2.40	2.53	2.39	
5		32.9	29.4	32.2	37.8	36.3		2.42	2.35	2.24	2.51	2.37	
6		32.2	28.5	32.7	39.6	36.3		2.38	2.34	2.32	2.58	2.41	
7		30.1	27.8	33.2	39.1	36.3		2.27	2.35	2.37	2.60	2.42	
8		32.1	28.6	31.5	37.4	36.7		2.42	2.40	2.31	2.54	2.46	
9		34.2	28.0	37.3	38.2	39.2		2.56	2.34	2.60	2.59	2.59	
10		33.3	27.0	39.6	37.4	39.9		2.48	2.30	2.66	2.50	2.60	
11		30.8	27.9	34.5	36.0	36.5		2.33	2.31	2.48	2.45	2.44	
12		31.9	27.8	33.9	37.5	39.9		2.43	2.35	2.41	2.52	2.63	
13		37.3	38.7	42.4	40.6	38.5		2.65	2.82	2.62	2.64	2.68	
14		36.5	46.4	36.4	33.4	47.7		2.57	2.89	2.44	2.39	2.88	
15		40.5	35.9	41.0	52.5	51.7		2.88	2.70	2.55	2.69	2.90	
16		38.9	37.6	40.4	68.3	63.5		2.82	2.76	2.53	2.82	3.06	
17		49.1	38.7	48.5	52.8	67.2		2.99	2.82	2.65	2.70	2.95	
18		58.0	43.6	53.3	52.3	57.1		2.89	2.81	2.53	2.71	2.81	
19		55.3	49.3	47.7	46.2	56.1		2.82	2.95	2.60	2.66	2.80	
20		55.4	43.6	50.0	54.0	50.2		2.85	2.80	2.68	2.81	2.84	
21		53.4	47.5	54.5	57.1	61.3		2.88	2.95	2.75	2.93	3.06	
22		50.4	48.3	53.1	53.3	59.0		2.84	3.12	2.90	3.01	3.30	
23		57.0	49.4	55.8	63.8	67.3		3.10	3.00	2.98	3.09	3.20	
24		52.7	45.8	54.6	52.2	60.4		3.16	2.86	3.15	2.80	3.23	
25		57.7	43.8	52.3	47.4	64.7		3.22	2.89	2.95	2.60	3.56	
26		48.0	39.2	49.5	49.4	61.0		2.79	2.63	2.81	2.76	3.25	
27		45.6	45.3	52.2	51.7	60.6		2.66	2.92	2.84	2.85	3.47	
28		40.5	44.1	42.5	59.0	57.9		2.62	2.93	2.56	3.35	3.11	
29		43.6	40.3	45.8	58.8	57.9		2.64	2.77	2.70	3.20	3.24	
30		43.8	39.4	47.8	52.5	60.4		2.87	2.79	2.95	3.12	3.37	
31		47.9	50.4	54.0	54.9	57.1		2.94	3.18	3.16	3.09	3.41	
32		53.2	42.7	60.5	24.2	65.2		3.08	3.07	3.55	3.00	3.29	
33		46.6	50.6	53.4	58.9	52.0		2.84	3.43	3.14	3.00	3.09	
34		48.0	48.5	54.4	65.6	53.8		2.85	3.15	3.29	3.00	3.10	
35		44.2	51.1	58.1	54.7	53.1		2.68	3.45	3.40	2.96	3.00	
36		46.6	50.4	58.2	63.5	58.8		2.57	3.27	3.34	3.35	3.20	
37		42.0	48.2	56.6	57.0	60.9		2.62	3.22	3.21	3.22	3.21	
38		44.6	46.9	55.4	57.9	56.1		2.60	3.00	3.17	3.14	3.00	
39		45.3	45.9	51.3	55.5	63.4		2.67	3.03	3.10	3.11	3.20	
40		49.4	44.8	59.5	58.1	59.8		3.07	3.01	3.10	3.33	3.01	
41		55.2	46.2	56.1	64.2	55.7		3.08	2.94	3.20	3.35	2.94	
42		45.4	45.7	62.1	62.6	57.2		2.80	2.90	3.24	3.19	3.08	
43		46.7	42.0	52.6	54.5	48.4		2.79	2.70	3.02	3.00	2.77	
44		42.8	34.2	48.1	46.3	51.1		2.73	2.41	2.81	2.80	3.01	
45		44.0	29.6	45.8	49.7	43.9		2.71	2.27	2.71	2.87	2.73	
46		37.7	35.5	42.9	45.8	41.5		2.52	2.47	2.66	2.80	2.74	
47		36.1	31.0	35.8	42.7	41.7		2.57	2.37	2.45	2.70	2.70	
48		36.6	29.7	39.4	41.5	40.1		2.46	2.28	2.56	2.75	2.64	
49		35.6	30.4	37.7	40.4	42.7		2.42	2.32	2.47	2.59	2.70	
50		34.6	32.1	37.6	39.4	44.2		2.32	2.43	2.46	2.49	2.83	
51		36.6	34.3	38.6	42.1	41.8		2.24	2.36	2.42	2.60	2.62	
52		52.3	38.7	43.3	39.7	40.9		2.24	2.16	2.22	2.53	2.49	
Total		2040.	2222.	2366.	2345.	2654.		2.72	2.67	2.72	2.82	2.89	

TABLE B-2 WEIGHT AND DENSITY DATA FOR ROUTE NO. 1

** WEIGHT PER HOUSEHOLD (LB/WK) ** DENSITY OF REFUSE (1000LB/LD)**											
** WEEK **	1966	1967	1968	1969	1970	** 1966	1967	1968	1969	1970	**
1	58.4	56.6	52.5	72.5	78.4	1.85	2.33	2.44	2.39	2.69	
2	49.7	46.5	53.2	69.0	67.3	1.78	2.13	2.61	2.45	2.48	
3	40.4	45.0	49.9	57.2	53.1	1.75	2.18	2.45	2.40	2.78	
4	39.8	40.8	48.5	48.8	47.0	1.82	1.98	2.38	2.50	2.60	
5	39.0	43.1	43.5	49.5	49.7	1.89	2.09	2.26	2.54	2.75	
6	38.1	41.6	37.9	51.9	58.6	1.96	2.14	1.97	2.66	3.24	
7	40.0	40.6	45.2	48.4	45.3	1.83	1.97	2.22	2.63	2.65	
8	34.6	43.3	40.4	47.2	48.5	1.90	2.10	2.10	2.56	2.54	
9	39.8	45.6	47.7	49.5	48.7	1.93	2.21	2.34	2.54	2.85	
10	32.9	41.5	50.9	40.5	52.6	1.81	2.01	2.50	2.20	3.08	
11	39.2	39.2	47.7	40.5	39.4	2.02	1.90	2.34	2.20	2.16	
12	35.5	40.2	45.0	43.5	48.3	1.95	1.95	2.21	2.36	2.67	
13	49.6	49.8	56.5	49.4	51.4	2.27	2.28	2.63	2.68	2.84	
14	69.3	45.4	46.8	42.7	64.7	2.48	2.08	2.30	2.32	3.22	
15	56.1	55.5	58.0	64.1	58.7	2.10	2.54	2.44	2.57	2.78	
16	51.9	55.3	52.0	96.8	84.7	2.25	2.68	2.42	3.08	3.01	
17	56.6	78.0	75.0	84.4	102.1	2.12	2.92	2.65	2.78	2.90	
18	54.4	90.5	85.5	60.8	91.9	1.95	2.76	2.36	2.44	2.77	
19	68.7	92.5	73.9	79.9	87.2	2.02	2.72	2.51	2.95	2.99	
20	69.8	90.5	83.1	86.6	74.6	2.30	2.76	3.06	3.33	3.09	
21	85.2	102.6	91.0	98.1	113.1	2.70	3.25	3.35	3.48	3.88	
22	97.0	95.7	108.1	97.0	104.5	3.63	2.92	3.82	3.89	3.71	
23	94.7	109.9	110.3	122.1	135.1	3.00	3.12	3.61	4.17	3.95	
24	91.1	109.2	103.6	111.5	105.3	3.00	3.21	3.52	3.81	3.88	
25	87.4	121.3	114.6	84.5	114.8	3.00	3.33	3.49	3.00	4.39	
26	74.8	113.1	100.7	81.3	113.5	2.80	3.21	3.42	3.00	4.18	
27	100.3	76.5	87.0	85.7	98.9	3.06	2.74	3.66	3.04	4.10	
28	89.3	71.9	79.1	99.6	111.6	2.94	2.69	3.04	3.83	4.27	
29	75.3	68.4	76.4	104.3	98.3	2.82	2.56	2.70	3.85	4.25	
30	84.1	76.2	87.8	92.2	106.7	3.01	2.99	3.88	3.70	4.42	
31	98.7	86.9	97.4	81.3	95.8	3.25	2.98	3.74	3.00	3.97	
32	83.8	112.5	98.2	32.5	125.7	2.76	3.86	4.13	3.00	4.63	
33	112.5	83.9	102.6	71.5	72.1	3.86	3.14	3.94	3.00	3.12	
34	105.4	81.2	91.8	81.4	90.8	3.47	3.04	3.86	2.89	4.30	
35	98.1	76.8	102.3	86.8	83.5	3.23	2.53	3.93	3.64	3.46	
36	85.9	78.3	89.4	94.0	81.8	3.37	2.58	3.59	3.77	3.13	
37	91.6	55.3	98.7	87.4	80.4	2.90	2.17	3.79	3.84	3.33	
38	78.7	61.2	84.3	83.2	73.1	2.70	2.40	3.24	3.49	3.16	
39	66.5	64.2	66.5	80.5	67.8	2.61	2.30	2.80	3.23	3.21	
40	61.1	73.2	81.2	82.3	94.3	2.65	2.74	3.26	3.45	3.35	
41	66.8	84.7	74.2	84.5	81.4	2.75	2.49	3.12	3.25	3.24	
42	89.2	70.5	108.0	108.3	86.6	2.72	2.64	3.67	3.70	3.19	
43	67.0	79.3	84.2	99.2	70.9	2.40	2.84	3.10	3.39	2.82	
44	54.4	70.9	73.1	59.8	67.5	2.24	2.54	2.69	2.76	3.05	
45	44.2	68.1	69.8	84.8	55.9	2.14	2.44	2.68	3.26	2.78	
46	52.1	57.5	57.0	61.1	56.1	2.26	2.63	2.29	2.82	2.79	
47	44.2	47.5	47.7	63.7	50.0	2.14	2.30	2.11	2.80	2.62	
48	43.7	50.7	50.8	63.4	51.1	2.00	2.61	2.14	3.08	2.54	
49	43.3	47.4	50.7	62.2	58.7	1.98	2.44	2.24	2.87	2.78	
50	50.7	48.7	60.7	56.6	51.3	2.32	2.36	2.44	2.75	2.55	
51	51.9	52.7	51.1	63.3	52.7	2.25	2.41	2.15	2.78	2.62	
52	60.3	79.9	61.8	56.1	49.8	2.16	2.27	2.10	2.59	2.36	

TABLE B-3 WEIGHT AND DENSITY DATA FOR ROUTE NO. 3

** WEEK **	** WEIGHT PER HOUSEHOLD (LB/WK) **					** DENSITY OF REFUSE (1000LB/LD) **					**
	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970	
1	35.4	43.8	41.1	53.5	58.8	1.98	2.56	2.18	2.08	2.53	
2	37.4	36.4	37.1	50.4	55.5	1.92	2.34	2.28	2.18	2.48	
3	29.4	36.4	36.5	41.8	46.8	2.10	2.34	2.37	1.95	2.59	
4	28.7	34.3	35.5	43.4	42.7	1.94	2.32	2.30	2.11	2.48	
5	27.4	35.8	32.2	34.8	40.1	1.96	2.42	2.21	2.14	2.45	
6	27.6	36.1	31.3	39.6	36.7	2.09	2.44	2.15	2.20	2.13	
7	27.6	30.3	40.5	38.9	38.9	1.97	2.05	2.78	2.27	2.38	
8	27.8	35.3	35.8	38.5	40.1	2.10	2.52	2.61	2.25	2.45	
9	29.1	35.3	45.6	37.8	43.9	2.08	2.52	2.96	2.45	2.55	
10	25.8	38.2	50.9	37.1	44.2	1.95	2.58	2.70	2.28	2.70	
11	27.4	30.9	42.6	37.1	42.4	2.07	2.09	2.76	2.28	2.46	
12	30.3	35.8	35.3	40.4	42.5	2.29	2.42	2.17	2.48	2.60	
13	40.2	41.6	44.6	45.2	36.3	2.46	2.67	2.48	2.64	2.48	
14	53.8	38.0	37.1	32.7	47.7	2.88	2.57	2.06	2.12	2.52	
15	43.0	42.6	47.7	64.1	51.3	2.63	2.88	2.53	2.77	2.48	
16	41.5	38.8	48.9	96.0	84.5	2.32	2.49	2.38	3.20	3.27	
17	47.3	51.0	66.2	70.2	108.5	2.64	2.98	2.76	2.73	3.07	
18	48.4	59.9	78.1	59.5	76.0	2.39	2.85	2.68	2.57	2.52	
19	60.7	71.2	63.8	67.1	77.6	2.60	2.77	2.48	2.70	2.73	
20	50.6	75.0	66.9	74.6	62.6	2.50	3.01	2.52	2.90	2.69	
21	71.1	71.5	68.3	76.4	79.4	3.26	3.06	2.95	3.30	2.88	
22	64.6	77.0	83.1	74.4	84.4	3.19	3.19	3.03	3.10	3.38	
23	51.4	81.1	80.0	94.6	105.3	3.00	3.36	3.01	3.45	3.82	
24	63.1	76.9	72.7	70.7	76.6	3.00	3.29	3.14	2.75	3.42	
25	56.3	75.9	78.9	60.6	85.1	2.78	3.61	2.97	2.62	3.80	
26	51.9	65.6	72.4	62.6	78.9	2.47	3.12	3.25	2.92	3.39	
27	60.5	56.8	64.1	59.2	67.7	2.68	2.92	3.25	3.14	3.57	
28	55.9	57.0	57.9	88.0	69.9	2.76	2.93	2.60	3.54	3.12	
29	53.1	51.4	50.6	76.9	79.2	2.73	2.64	2.81	3.45	3.83	
30	50.6	53.0	56.3	60.7	74.9	2.50	2.96	3.46	3.22	3.95	
31	56.8	53.9	66.2	64.3	69.3	3.17	2.77	3.22	3.00	4.02	
32	60.4	66.2	73.5	28.3	84.9	3.10	3.40	3.30	3.00	3.94	
33	61.3	68.1	66.6	54.0	66.2	3.28	3.24	2.88	3.00	3.20	
34	62.8	59.5	69.9	69.9	55.7	3.36	3.32	3.02	3.02	3.08	
35	61.0	54.1	76.1	59.6	68.0	2.90	2.78	3.17	3.16	3.43	
36	63.6	54.2	71.8	69.0	70.9	3.40	2.90	3.49	3.22	3.43	
37	59.6	50.8	82.6	65.0	75.3	3.19	2.61	3.57	3.79	3.36	
38	63.2	51.6	74.0	68.7	59.9	3.12	2.88	3.32	3.34	2.90	
39	57.4	52.2	60.8	60.4	70.9	2.95	2.68	2.73	2.82	3.43	
40	48.2	52.1	71.7	64.7	74.1	2.69	2.79	3.10	3.02	3.31	
41	54.8	61.7	74.4	87.0	67.0	2.93	3.17	3.34	3.76	3.11	
42	58.5	50.8	82.9	75.9	72.6	2.78	2.51	3.72	3.28	3.51	
43	47.5	47.3	75.3	69.1	59.9	2.26	2.53	2.93	2.78	2.90	
44	36.6	47.5	63.4	54.7	55.7	2.14	2.44	2.74	2.90	3.08	
45	29.7	48.6	59.6	60.1	47.2	2.12	2.40	2.78	2.42	2.74	
46	43.5	38.3	56.3	57.6	43.6	2.94	2.34	2.74	2.69	2.98	
47	35.4	35.0	41.1	44.9	43.4	2.53	2.50	2.40	2.28	2.65	
48	35.0	34.5	43.5	44.6	40.8	2.37	2.46	2.31	2.89	2.37	
49	35.6	34.0	45.6	50.2	43.7	2.41	2.43	2.22	2.79	2.54	
50	38.6	33.5	49.5	41.0	44.4	2.61	2.39	2.31	2.52	2.58	
51	38.9	31.8	47.3	48.4	48.1	2.38	2.04	2.30	2.57	2.54	
52	44.1	57.8	47.2	41.3	42.9	2.10	2.32	2.12	2.41	2.62	

TABLE B-4 WEIGHT AND DENSITY DATA FOR ROUTE NO. 7

** WEEK	** WEIGHT PER HOUSEHOLD (LB/WK)					** DENSITY OF REFUSE (1000LB/LD)**					**
	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970	
1	38.9	38.6	34.1	44.5	38.4	2.01	2.35	2.25	2.35	2.42	
2	39.7	27.3	41.3	45.5	50.8	2.13	1.91	2.48	2.40	2.56	
3	29.4	30.7	33.3	35.0	39.8	2.16	1.87	2.20	2.10	2.51	
4	31.5	26.2	32.5	36.1	35.1	2.09	2.04	2.68	2.65	2.48	
5	31.5	33.6	30.0	30.0	37.4	2.31	2.35	2.20	2.33	2.54	
6	33.4	30.9	34.1	34.4	35.2	2.22	2.40	2.50	2.52	2.70	
7	26.7	29.4	29.4	35.2	33.2	2.07	2.06	2.28	2.58	2.55	
8	29.2	27.2	29.9	33.0	37.6	2.26	2.24	2.47	2.56	2.55	
9	31.5	34.7	36.4	32.8	39.1	2.09	2.31	2.67	2.55	2.76	
10	26.7	29.9	37.7	33.5	38.5	1.96	2.20	2.37	2.60	2.72	
11	27.2	30.8	34.0	33.0	36.8	2.00	2.27	2.49	2.56	2.71	
12	27.2	27.5	33.3	37.0	37.4	2.00	2.14	2.20	2.57	2.87	
13	38.9	37.1	43.6	38.0	36.4	2.36	2.36	2.74	2.39	3.06	
14	51.5	32.7	35.4	25.0	50.5	2.87	2.18	2.46	2.06	3.30	
15	40.4	36.5	40.0	49.3	49.2	2.35	2.55	2.20	2.60	3.10	
16	41.0	41.2	36.1	68.7	74.5	2.38	2.40	2.38	2.59	3.55	
17	42.3	43.6	53.9	53.9	78.3	2.36	2.54	2.45	2.45	3.29	
18	51.0	65.4	59.4	41.7	66.5	2.54	2.95	2.61	2.50	3.01	
19	50.4	46.9	47.4	50.0	64.5	2.51	2.34	2.50	2.75	3.25	
20	54.3	57.8	53.4	54.0	56.6	2.91	2.31	2.61	2.74	3.22	
21	54.6	64.6	55.6	62.4	69.4	2.93	3.01	2.62	2.94	3.40	
22	55.9	60.8	59.8	52.8	67.4	3.12	3.27	2.92	3.03	4.25	
23	60.3	70.5	63.1	66.3	80.1	3.00	3.52	3.20	3.24	3.82	
24	51.6	59.7	59.5	57.6	68.4	3.00	3.48	3.27	3.04	4.02	
25	37.7	68.8	57.7	41.2	68.2	3.09	3.56	2.93	2.59	4.01	
26	45.2	52.5	50.0	49.3	65.7	2.74	3.06	2.75	2.83	3.41	
27	51.5	51.1	52.7	56.4	58.9	2.99	2.75	2.78	3.10	4.00	
28	48.1	38.3	48.5	52.3	71.1	3.05	2.82	2.91	3.63	3.92	
29	49.5	49.7	42.3	63.5	68.9	3.00	2.78	2.54	3.49	3.92	
30	43.3	43.9	46.2	50.0	68.2	3.02	2.67	2.90	3.30	4.30	
31	63.8	48.4	50.7	47.7	61.9	3.56	2.94	3.04	3.00	4.20	
32	56.5	58.0	64.6	15.9	69.8	3.15	3.38	3.55	3.00	3.62	
33	64.6	47.4	56.7	68.2	56.3	3.60	2.76	3.40	3.00	3.55	
34	56.1	46.3	55.9	59.7	55.2	3.01	2.59	3.69	3.15	3.36	
35	59.7	44.5	64.0	57.9	53.9	3.20	2.49	3.67	3.32	3.40	
36	54.7	46.0	59.4	61.7	61.8	3.18	2.80	3.73	3.70	3.52	
37	65.4	41.3	61.2	53.4	64.3	3.80	2.75	3.67	3.20	3.66	
38	60.4	42.0	62.1	60.3	58.5	3.24	2.35	3.56	3.18	3.33	
39	53.6	44.1	52.4	57.3	65.7	2.99	2.68	3.14	3.15	3.51	
40	48.7	46.5	64.4	63.5	65.7	2.95	2.71	3.40	3.35	3.22	
41	52.5	47.4	62.2	71.2	61.1	3.18	2.88	3.42	3.48	3.08	
42	53.3	51.1	67.1	63.5	61.9	3.23	2.55	3.16	3.35	3.31	
43	53.4	46.3	55.9	59.5	51.9	2.76	2.40	3.07	3.02	3.05	
44	37.1	42.0	50.4	45.0	50.8	2.35	2.45	2.77	2.83	3.20	
45	32.5	41.9	47.9	53.5	41.6	2.39	2.44	2.75	3.21	2.94	
46	36.4	35.3	40.6	47.0	38.1	2.21	2.47	2.82	3.10	3.06	
47	32.4	27.0	33.3	41.8	40.4	2.15	1.99	2.31	2.76	3.10	
48	31.9	30.6	39.6	37.4	36.6	2.34	2.52	2.90	2.74	2.94	
49	31.6	32.9	37.1	35.3	38.7	2.32	2.30	2.58	2.45	2.85	
50	33.8	30.0	34.7	37.6	33.6	2.48	1.91	2.41	2.61	2.70	
51	35.5	31.7	33.3	35.2	38.8	2.61	1.93	2.44	2.58	2.74	
52	37.5	49.4	40.5	31.0	32.8	2.09	2.38	2.14	2.41	2.32	

TABLE B-5 WEIGHT AND DENSITY DATA FOR ROUTE NO.30

		** WEIGHT PER HOUSEHOLD (LB/WK) **					** DENSITY OF REFUSE (1000LB/LD) **						
** WEEK **	**	1966	1967	1968	1969	1970	**	1966	1967	1968	1969	1970	**
1		45.5	46.9	55.9	58.9	65.8		2.37	2.35	2.87	2.63	2.57	
2		45.5	46.3	52.0	48.4	58.1		2.37	2.41	3.00	2.68	2.69	
3		43.6	45.1	53.4	52.0	47.0		2.46	2.44	2.96	2.88	2.45	
4		38.6	38.5	50.9	47.5	48.0		2.49	2.17	2.94	2.74	2.50	
5		42.0	49.5	47.3	51.1	46.6		2.37	2.68	2.85	2.95	2.43	
6		40.8	42.8	48.8	52.0	49.1		2.63	2.32	2.94	3.00	2.56	
7		40.2	39.3	47.0	49.2	49.3		2.27	2.13	2.96	2.84	2.68	
8		43.3	44.0	46.1	48.3	47.9		2.55	2.38	2.78	2.91	2.72	
9		43.8	48.8	51.5	50.1	51.0		2.58	2.64	3.24	3.02	2.77	
10		40.1	43.6	54.2	53.4	54.1		2.36	2.36	3.41	2.96	2.94	
11		39.6	41.4	52.4	50.4	49.4		2.33	2.24	3.30	2.91	2.81	
12		40.8	42.4	48.0	53.9	50.9		2.51	2.21	2.89	3.11	3.03	
13		53.4	52.1	49.8	55.6	51.0		3.14	2.94	3.00	3.08	2.90	
14		53.8	53.4	52.7	49.7	57.8		2.91	2.78	2.92	2.87	3.01	
15		52.5	56.3	49.2	64.5	64.5		2.96	3.46	2.84	3.31	3.36	
16		50.5	53.0	54.8	71.5	67.4		2.63	3.12	3.30	3.30	3.37	
17		49.5	59.1	59.4	59.1	72.0		2.68	3.33	3.29	3.03	3.46	
18		55.3	64.2	62.4	63.4	68.4		2.88	3.10	2.70	3.38	2.95	
19		56.3	61.5	60.7	62.9	67.2		2.82	3.08	2.90	3.11	3.00	
20		52.3	62.9	54.1	62.2	65.9		2.72	3.04	3.12	2.87	3.05	
21		45.7	57.1	53.1	60.6	66.6		2.38	2.86	2.83	2.80	3.20	
22		58.4	52.8	52.1	60.7	65.3		3.16	2.75	3.14	2.90	3.40	
23		62.1	63.4	58.7	62.2	67.4		3.00	3.43	3.25	2.78	3.24	
24		73.2	61.9	61.0	56.6	66.1		3.00	3.35	3.84	2.80	3.44	
25		46.7	61.3	56.5	62.8	69.9		2.53	3.32	3.40	2.90	3.64	
26		47.8	56.0	52.5	54.6	62.6		2.81	3.03	3.16	2.70	3.26	
27		49.1	54.2	58.9	58.2	72.2		2.89	2.82	3.40	2.88	3.61	
28		48.4	50.2	50.5	61.2	62.6		2.85	2.83	3.04	3.14	3.26	
29		43.5	49.1	52.7	56.7	61.2		2.56	2.89	3.04	2.91	3.48	
30		48.6	52.2	53.1	57.1	60.4		2.74	3.07	3.50	2.93	3.28	
31		50.9	54.4	52.1	62.8	63.6		3.13	3.20	3.14	2.90	3.31	
32		48.6	63.5	58.4	36.8	64.5		2.74	3.58	3.52	3.00	2.78	
33		52.2	59.2	55.6	36.8	50.6		3.21	3.08	2.96	3.00	2.75	
34		51.3	52.1	57.9	65.0	57.8		2.67	2.94	3.34	3.00	3.14	
35		60.0	52.3	55.6	52.6	58.6		2.90	3.08	3.67	2.80	3.05	
36		54.6	52.8	70.0	64.3	64.8		3.08	2.98	4.04	3.30	3.24	
37		49.2	43.8	55.9	55.8	61.2		2.56	2.58	3.10	3.36	3.06	
38		52.1	49.6	58.7	52.8	52.1		2.71	2.92	3.39	3.18	2.96	
39		49.7	53.0	58.9	50.3	61.6		2.40	3.12	3.40	3.03	3.21	
40		52.9	57.4	64.5	57.8	60.8		2.65	3.53	3.31	3.20	3.04	
41		53.1	62.6	62.8	60.9	64.7		2.66	3.39	3.48	2.91	2.89	
42		50.9	53.6	76.6	61.6	61.6		2.55	3.02	3.42	2.94	3.08	
43		49.9	55.9	58.1	54.1	59.0		2.41	3.15	3.50	3.00	2.95	
44		47.1	55.9	61.9	52.7	58.8		2.36	3.15	3.57	2.92	2.94	
45		38.7	55.9	57.8	53.2	53.8		2.28	3.29	3.20	2.73	2.80	
46		43.2	50.1	51.3	52.7	50.8		2.34	3.08	2.84	2.92	2.76	
47		45.1	54.7	47.8	47.6	52.0		2.35	3.22	3.01	3.00	2.71	
48		36.2	48.8	54.2	47.6	49.1		2.04	2.87	3.13	3.00	2.56	
49		38.6	48.9	52.1	52.0	52.6		2.27	2.76	3.01	3.00	2.74	
50		43.8	47.1	45.0	46.5	54.7		2.37	2.77	2.60	2.80	2.85	
51		44.3	53.4	50.2	47.8	50.9		2.40	2.89	2.90	2.88	2.65	
52		44.9	66.5	50.8	42.1	48.0		2.34	2.57	2.27	2.78	2.40	

TABLE B-6 WEIGHT AND DENSITY DATA FOR ROUTE NO.31

		** WEIGHT PER HOUSEHOLD (LB/WK)					** DENSITY OF REFUSE (1000LB/LD)**						
** WEEK	**	1966	1967	1968	1969	1970	** 1966	1967	1968	1969	1970	**	**
1		50.8	47.6	46.2	58.3	80.5	2.37	2.22	2.22	2.41	2.45		
2		47.2	44.3	44.8	57.5	80.2	2.45	2.30	2.44	2.33	3.01		
3		40.8	44.2	46.4	55.9	53.7	2.31	2.50	2.40	2.57	2.28		
4		38.2	42.2	44.4	54.0	48.2	2.23	2.46	2.48	2.54	2.16		
5		43.7	46.4	38.2	53.5	54.1	2.33	2.71	2.26	2.70	2.30		
6		36.4	42.6	42.1	56.4	57.2	2.19	2.65	2.42	2.71	2.43		
7		39.4	42.3	41.1	49.4	55.1	2.45	2.47	2.50	2.69	2.34		
8		37.5	44.9	39.9	48.4	52.8	2.26	2.62	2.43	2.44	2.37		
9		39.6	47.5	43.5	50.7	49.5	2.24	2.77	2.57	2.62	2.22		
10		34.9	48.8	49.8	51.3	59.1	2.17	2.94	2.71	2.65	2.51		
11		35.7	47.2	44.7	47.6	45.5	2.30	2.84	2.64	2.46	2.04		
12		37.3	47.7	43.9	48.5	47.9	2.25	2.70	2.52	2.51	2.15		
13		47.2	52.1	46.2	53.3	47.5	2.59	2.70	2.58	2.69	2.19		
14		47.6	53.6	46.7	47.2	59.4	2.54	2.50	2.54	2.38	2.46		
15		41.3	51.7	44.8	60.0	67.3	2.27	2.61	2.44	2.64	2.65		
16		44.3	50.3	53.1	61.8	68.4	2.43	2.54	2.68	2.72	2.76		
17		46.3	63.7	54.7	61.7	65.0	2.62	2.83	2.76	2.90	2.44		
18		52.9	54.1	55.3	55.9	60.9	2.47	2.66	2.60	2.82	2.52		
19		48.7	63.5	57.0	56.2	61.0	2.60	3.04	2.62	2.64	2.29		
20		45.8	61.5	50.0	54.2	54.4	2.59	2.67	2.65	2.49	2.25		
21		49.2	48.0	51.4	56.6	57.5	2.70	2.80	2.53	2.72	2.32		
22		63.4	58.1	49.1	53.6	57.7	3.20	2.78	2.54	2.77	2.39		
23		59.5	60.7	52.6	61.3	62.9	3.00	2.98	2.53	2.64	2.36		
24		56.5	51.4	50.7	57.7	55.1	3.10	2.74	2.62	2.65	2.28		
25		51.6	58.0	47.5	53.0	63.3	2.75	2.85	2.52	2.49	2.76		
26		43.4	48.6	48.3	49.9	56.5	2.53	2.52	2.27	2.40	2.40		
27		53.8	55.3	50.5	54.0	58.2	2.87	2.58	2.43	2.48	2.61		
28		49.5	41.3	48.4	61.1	64.2	2.72	2.41	2.50	3.01	2.59		
29		44.4	45.5	44.9	56.0	58.0	2.44	2.36	2.58	2.63	2.53		
30		45.8	47.9	49.6	57.5	58.9	2.67	2.63	2.70	2.83	2.57		
31		59.6	54.1	61.8	58.0	57.6	2.65	2.66	3.04	2.79	2.82		
32		44.7	69.6	64.4	42.1	59.8	2.69	3.02	3.33	3.00	2.54		
33		57.0	54.6	53.1	53.7	56.8	3.13	2.68	2.97	3.00	2.62		
34		50.2	50.7	53.8	78.4	54.1	2.84	2.49	3.09	3.00	2.57		
35		57.9	46.5	57.5	57.0	52.9	3.09	2.41	2.97	2.62	2.44		
36		52.7	49.0	62.4	71.5	56.0	2.66	2.08	2.93	3.08	2.38		
37		51.8	43.9	55.9	67.0	60.0	3.02	2.10	2.89	3.01	2.55		
38		51.6	48.2	56.5	61.4	54.9	2.75	2.25	3.16	2.70	2.46		
39		52.5	52.3	58.8	61.0	62.0	2.80	2.57	3.12	2.74	2.86		
40		55.2	54.9	60.7	64.0	60.5	2.86	4.10	3.06	2.94	2.57		
41		48.9	54.7	63.1	64.9	63.5	2.61	2.62	3.26	3.12	2.63		
42		54.7	45.0	68.3	64.1	60.2	2.76	2.80	3.36	2.88	2.49		
43		50.1	52.5	52.6	56.6	52.0	2.60	2.80	2.72	2.66	2.33		
44		48.0	51.8	57.5	52.6	65.2	2.56	3.02	2.90	2.53	2.77		
45		38.9	47.2	52.5	55.6	57.5	2.20	2.52	2.65	2.50	2.32		
46		49.0	43.1	48.1	53.9	48.4	2.47	2.12	2.55	2.72	2.44		
47		43.9	51.0	45.7	52.2	55.5	2.34	2.72	2.49	2.51	2.42		
48		41.2	46.3	44.5	57.0	51.8	2.33	2.40	2.42	2.74	2.39		
49		44.4	49.5	44.8	51.0	59.0	2.37	2.43	2.44	2.51	2.38		
50		44.8	46.3	47.1	50.2	63.6	2.46	2.40	2.50	2.47	2.70		
51		47.4	46.4	50.9	55.3	54.6	2.39	2.22	2.63	2.54	2.45		
52		44.8	55.4	61.2	52.4	53.9	2.09	2.07	2.30	2.41	2.29		

TABLE B-7 WEIGHT AND DENSITY DATA FOR ROUTE NO.42

** WEEK **	** WEIGHT PER HOUSEHOLD (LB/WK) **					** DENSITY OF REFUSE (1000LB/LD) **					**
	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970	
1	0.0	36.8	39.6	59.8	42.4	0.00	2.55	2.14	2.33	2.43	
2	0.0	34.6	43.7	48.8	45.3	0.00	2.63	2.29	2.92	2.44	
3	0.0	39.8	42.0	45.7	35.8	0.00	2.54	2.27	2.47	2.43	
4	0.0	34.4	41.0	42.0	34.1	0.00	2.61	2.29	2.43	2.50	
5	0.0	41.9	31.9	40.8	37.4	0.00	2.67	1.98	2.36	2.45	
6	0.0	44.2	39.3	44.2	37.3	0.00	2.71	2.06	2.39	2.36	
7	0.0	36.7	36.9	46.0	40.3	0.00	2.25	2.69	2.41	2.64	
8	0.0	36.6	39.1	39.2	32.4	0.00	2.54	2.62	2.35	2.20	
9	0.0	39.0	46.4	42.2	37.3	0.00	2.96	2.99	2.53	2.44	
10	0.0	38.9	50.4	41.7	38.4	0.00	2.82	3.02	2.69	2.27	
11	0.0	37.0	44.0	40.8	34.2	0.00	2.36	2.95	2.36	2.24	
12	0.0	45.8	39.2	38.2	39.3	0.00	3.04	2.74	2.67	2.48	
13	0.0	39.0	51.6	41.4	39.8	0.00	2.83	3.09	2.48	2.43	
14	0.0	43.8	50.6	39.5	47.0	0.00	2.59	3.03	2.55	2.87	
15	0.0	51.3	54.1	54.1	54.9	0.00	3.03	3.13	2.59	2.58	
16	0.0	44.5	51.6	68.0	61.8	0.00	2.84	3.09	2.85	3.06	
17	0.0	54.9	52.7	58.7	68.5	0.00	2.92	2.85	2.98	3.30	
18	0.0	71.3	71.4	48.5	62.0	0.00	2.99	2.85	2.71	2.99	
19	0.0	75.4	64.9	58.5	64.0	0.00	2.93	2.79	2.80	2.86	
20	0.0	76.6	60.5	50.2	52.9	0.00	3.39	2.90	2.63	2.85	
21	0.0	74.3	60.4	61.4	66.4	0.00	3.70	2.98	2.78	3.04	
22	0.0	52.3	55.7	45.8	56.5	0.00	2.69	2.83	2.65	3.34	
23	0.0	60.4	63.6	55.9	64.6	0.00	2.92	2.96	2.68	3.20	
24	0.0	53.8	57.5	51.2	59.9	0.00	2.86	3.11	2.60	3.05	
25	0.0	63.3	54.7	48.2	67.5	0.00	2.97	2.78	2.45	3.17	
26	0.0	52.1	59.7	48.3	61.0	0.00	2.77	2.86	2.61	2.94	
27	0.0	58.4	48.5	51.2	64.3	0.00	2.82	2.81	2.77	3.57	
28	0.0	48.7	45.1	59.9	57.3	0.00	2.59	2.52	3.14	3.18	
29	0.0	50.2	49.3	58.6	55.2	0.00	2.67	2.95	3.07	3.16	
30	0.0	51.1	49.6	58.4	64.3	0.00	3.02	3.08	3.06	3.27	
31	0.0	56.7	60.1	59.1	54.6	0.00	3.12	3.60	3.00	3.45	
32	0.0	68.6	62.8	28.6	62.6	0.00	3.53	3.90	3.00	3.10	
33	0.0	54.8	59.3	60.8	54.7	0.00	3.12	3.68	3.00	3.34	
34	0.0	55.5	59.2	70.9	59.8	0.00	2.95	3.82	2.97	3.42	
35	0.0	56.2	60.9	55.1	57.5	0.00	3.09	3.78	2.64	3.29	
36	0.0	50.8	58.7	62.6	63.5	0.00	2.70	3.28	3.18	3.42	
37	0.0	49.8	56.2	58.2	61.7	0.00	2.94	3.14	3.15	3.14	
38	0.0	54.2	63.2	56.4	62.0	0.00	2.79	3.42	2.78	3.07	
39	0.0	56.2	60.3	60.4	70.8	0.00	2.80	3.37	3.07	3.24	
40	0.0	63.5	67.4	61.7	70.2	0.00	3.49	3.23	3.04	3.06	
41	0.0	61.8	60.7	66.0	59.4	0.00	3.08	3.39	2.99	2.94	
42	0.0	56.2	72.7	69.5	51.4	0.00	2.89	3.48	3.33	2.77	
43	0.0	56.6	63.6	57.7	52.6	0.00	2.91	3.23	2.93	2.92	
44	0.0	51.9	50.8	45.4	54.2	0.00	2.67	2.84	2.72	3.01	
45	0.0	48.6	49.9	52.9	47.7	0.00	2.50	2.70	2.86	2.82	
46	0.0	42.0	44.2	47.6	46.4	0.00	2.48	2.47	2.75	2.74	
47	0.0	38.1	38.0	51.2	43.2	0.00	2.64	2.45	2.86	2.64	
48	0.0	42.1	41.4	40.8	43.2	0.00	2.40	2.48	2.85	2.64	
49	0.0	41.6	41.2	44.8	45.4	0.00	2.29	2.47	2.59	2.52	
50	0.0	36.0	42.2	41.5	44.5	0.00	2.05	2.36	2.58	2.72	
51	0.0	40.7	40.6	42.1	43.2	0.00	2.03	2.35	2.52	2.73	
52	0.0	57.6	46.3	43.9	42.6	0.00	2.04	2.10	2.63	2.69	

TABLE B-8 WEIGHT AND DENSITY DATA FOR ROUTE NO.47

		** WEIGHT PER HOUSEHOLD (LB/WK) **					** DENSITY OF REFUSE (1000LB/LD)**						
** WEEK **		1966	1967	1968	1969	1970	** 1966	1967	1968	1969	1970	**	
1		40.8	41.8	36.1	63.4	57.0	2.23	2.10	2.17	2.51	2.50		
2		42.8	32.2	41.6	52.6	51.3	2.34	2.06	2.28	2.80	2.49		
3		38.1	34.4	37.3	36.8	39.9	2.44	2.13	2.17	2.21	2.45		
4		32.5	35.9	37.1	45.4	36.7	2.32	2.30	2.47	2.56	2.60		
5		34.8	31.6	31.3	44.0	37.6	2.23	2.26	2.16	2.56	2.31		
6		32.0	31.8	32.7	40.9	38.2	2.83	2.36	2.44	2.38	3.20		
7		29.6	30.7	30.0	43.1	37.2	2.39	2.38	2.15	2.51	2.86		
8		29.4	33.0	32.5	40.9	33.8	3.04	2.45	2.42	2.46	2.83		
9		25.8	34.5	37.4	40.6	40.5	2.66	2.67	2.58	2.52	2.87		
10		27.1	35.0	38.6	37.5	38.5	2.96	2.50	2.48	2.25	2.96		
11		34.0	34.8	32.7	42.5	38.2	2.75	2.81	2.44	2.40	2.82		
12		29.3	34.0	34.4	40.9	39.3	2.18	2.34	2.56	2.46	3.15		
13		51.1	41.2	45.9	45.4	37.9	2.71	2.64	2.59	2.64	2.91		
14		57.7	37.2	31.1	34.4	50.9	2.55	2.38	2.32	2.37	3.35		
15		38.9	42.1	49.5	63.5	60.9	2.49	2.79	2.71	2.75	3.40		
16		45.1	41.3	40.6	74.0	75.4	2.62	2.95	2.61	2.70	3.56		
17		45.1	56.1	59.2	62.8	83.3	2.62	2.67	2.90	2.85	3.41		
18		64.1	65.7	55.5	46.6	63.8	3.50	2.49	2.20	2.80	2.94		
19		73.5	60.4	46.4	54.1	69.6	3.50	2.95	2.40	2.80	3.29		
20		61.7	63.4	57.8	50.0	57.5	3.47	3.18	2.91	3.00	3.21		
21		71.6	72.9	58.7	61.0	56.9	3.50	2.88	2.60	3.34	2.76		
22		65.6	63.6	60.1	58.1	61.8	3.48	2.88	2.60	3.73	3.56		
23		69.6	66.2	53.1	71.6	81.9	3.40	3.15	2.60	3.60	3.77		
24		58.6	59.4	50.3	59.4	74.3	3.20	3.34	2.60	3.25	3.80		
25		52.7	73.1	47.5	50.3	73.1	2.88	3.77	2.60	3.12	3.96		
26		52.7	58.8	48.9	55.8	59.8	2.88	2.95	2.60	3.35	3.06		
27		58.6	51.6	50.3	56.7	58.6	3.20	2.59	2.60	3.30	3.60		
28		50.8	39.6	45.0	69.0	69.4	3.40	2.45	2.74	3.78	3.55		
29		55.8	54.4	43.4	67.6	58.9	3.24	2.73	2.45	3.70	3.50		
30		56.4	49.9	47.5	56.4	64.3	3.38	3.09	2.95	3.62	3.70		
31		63.2	57.4	48.3	50.8	77.9	3.17	3.33	3.00	3.05	4.95		
32		54.7	60.9	48.3	27.4	68.1	3.50	3.14	3.00	3.00	3.06		
33		74.9	55.5	52.1	53.2	64.0	3.86	3.22	3.13	3.00	3.47		
34		57.5	56.4	58.0	74.9	62.7	3.05	2.99	3.27	3.10	3.50		
35		64.6	49.5	64.6	52.2	58.9	3.75	2.87	3.76	2.86	3.50		
36		74.7	54.5	60.2	65.2	66.5	3.75	2.53	3.50	3.68	3.50		
37		61.9	46.0	61.7	58.3	66.5	3.59	2.67	3.28	3.50	3.50		
38		61.4	50.5	62.0	43.2	61.1	3.08	2.76	3.30	3.50	3.41		
39		61.1	46.4	58.4	56.4	73.6	3.15	2.87	3.40	3.50	3.57		
40		52.4	50.4	70.2	61.2	67.2	2.86	3.02	3.44	3.80	3.26		
41		55.6	56.2	58.7	64.2	64.7	2.87	3.07	3.12	3.32	3.22		
42		64.1	48.8	60.8	69.1	66.0	3.05	3.02	2.90	3.30	3.20		
43		51.2	50.2	57.5	62.2	54.8	2.50	3.11	3.15	3.86	3.26		
44		39.5	46.1	60.4	47.6	47.1	2.62	3.17	2.96	3.28	2.80		
45		40.2	47.2	40.5	52.9	48.6	2.49	2.74	2.90	3.18	3.32		
46		41.8	41.6	56.5	43.5	41.1	2.68	2.97	2.92	2.70	3.03		
47		36.4	38.1	38.0	44.3	34.5	2.60	2.72	2.95	3.30	2.65		
48		37.5	37.4	41.2	38.0	43.9	2.40	2.48	2.74	2.83	2.61		
49		34.9	33.4	37.7	42.3	41.9	2.59	2.39	2.70	3.15	2.66		
50		37.4	32.7	37.4	40.4	43.3	2.48	2.34	2.49	2.79	2.75		
51		40.2	37.2	40.3	41.6	41.5	2.49	2.16	2.42	2.67	2.64		
52		50.0	55.9	49.2	39.6	44.6	2.02	2.12	2.35	2.73	2.65		

TABLE B-9 TRAVELLING DATA - SOUTHSIDE TO SOUTHSIDE DUMP

SOUTHSIDE DUMP LOCATION X=1.56, Y=-3.88

ROUTE	LOCATION		L-METRIC DISTANCE	TRUE DISTANCE	TRAVELLING TIME
	X	Y			
36	-1.93	-0.87	6.38	6.80	50.00
37	-2.48	-1.90	5.97	6.00	47.00
38	-1.60	-2.01	4.91	5.00	43.00
39	-0.90	-2.91	3.38	3.50	35.00
40	-0.98	-1.50	4.66	4.70	39.00
41	-0.87	-0.84	5.37	5.30	51.00
42	-0.24	-1.25	4.22	3.20	39.00
43	0.00	-2.04	3.30	4.00	35.00
44	1.09	-2.48	2.04	2.90	31.00
45	0.92	-1.33	3.30	3.80	33.00
46	0.60	-0.51	4.39	4.80	42.00
47	1.28	-0.68	3.54	4.10	35.00
51	2.15	-0.19	4.31	4.80	39.00
53	-1.71	-3.10	3.98	3.70	42.00
54	2.10	-1.11	3.38	4.00	32.00
55	-1.36	-4.28	4.11	5.10	45.00
56	-3.68	-3.81	6.27	6.50	51.00
57	-2.34	-3.84	4.71	5.60	45.00

DISTANCES ARE GIVEN IN MILES,
TIME IS FOR ROUND TRIP IN MINUTES.

TABLE B-10 TRAVELLING DATA - SOUTHSIDE TO INCINERATOR

INCINERATOR LOCATION X=0.00, Y=0.00

ROUTE	LOCATION		L-METRIC DISTANCE	TRUE DISTANCE	TRAVELLING TIME
	X	Y			
36	-1.93	-0.87	2.80	3.40	41.00
37	-2.48	-1.90	4.39	4.40	46.00
38	-1.60	-2.01	3.62	4.00	42.00
39	-0.90	-2.91	3.81	4.40	44.00
40	-0.98	-1.50	2.48	2.80	41.00
41	-0.87	-0.84	1.71	2.40	30.00
42	-0.24	-1.25	1.50	2.50	33.00
43	0.00	-2.04	2.04	3.60	39.00
44	1.09	-2.48	3.57	3.40	42.00
45	0.92	-1.33	2.26	2.50	37.00
46	0.60	-0.51	1.11	1.50	29.00
47	1.28	-0.68	1.96	2.30	37.00
48	1.28	0.73	2.01	2.20	33.00
49	2.20	1.14	3.35	3.70	37.00
50	2.78	1.03	3.81	4.20	40.00
51	2.15	-0.19	2.34	2.70	39.00
53	-1.71	-3.10	4.82	5.20	50.00
54	2.10	-1.11	3.21	3.70	43.00
55	-1.36	-4.28	5.64	6.70	52.00
56	-3.68	-3.81	7.50	8.10	59.00
57	-2.34	-3.84	6.19	6.60	53.00

DISTANCES ARE GIVEN IN MILES,
TIME IS FOR ROUND TRIP IN MINUTES.

TABLE B-11 TRAVELLING DATA - NORTHSIDE TO INCINERATOR

INCINERATOR LOCATION X=0.00, Y=0.00

ROUTE	LOCATION		L-METRIC DISTANCE	TRUE DISTANCE	TRAVELLING TIME
	X	Y			
1	-3.46	-1.14	4.60	7.50	54.00
5	-3.24	0.62	3.87	6.50	47.00
6	-2.50	0.84	3.35	5.50	42.00
7	-3.00	1.41	4.41	5.40	44.00
8	-3.08	2.12	5.20	6.20	46.00
10	-2.78	3.05	5.83	7.60	50.00
11	-2.37	2.23	4.60	7.10	46.00
12	-1.80	1.60	3.40	3.60	47.00
13	-0.81	2.23	3.05	4.10	43.00
14	-2.86	4.33	7.20	6.70	65.00
15	-2.61	3.73	6.35	6.20	60.00
16	-1.36	4.33	5.70	6.80	58.00
17	-1.36	3.73	5.10	6.50	55.00
18	-0.10	4.00	4.11	5.50	52.00
19	0.65	3.68	4.33	5.00	52.00
20	1.20	2.97	4.17	5.30	47.00
21	2.18	2.78	4.96	5.10	54.00
22	1.74	2.15	3.90	4.00	44.00
23	0.38	1.33	1.71	2.50	32.00
24	0.19	3.10	3.30	5.30	42.00
25	-0.81	0.00	0.81	1.90	30.00
26	-0.87	0.60	1.47	1.90	29.00
27	-0.27	0.73	1.00	2.50	30.00
28	1.00	4.11	5.12	6.60	53.00
29	2.31	3.54	5.86	6.20	55.00
30	-1.52	0.32	1.85	1.70	36.00
31	-1.30	1.11	2.42	2.80	37.00
32	-0.27	1.28	1.55	2.10	32.00
33	-0.27	2.15	2.42	3.00	40.00
34	0.27	2.15	2.42	3.60	41.00
35	0.00	2.70	2.70	3.70	40.00
52	3.27	2.37	5.64	5.80	56.00
58	2.04	7.14	7.14	7.40	61.00
59	0.54	5.64	5.64	6.00	59.00

DISTANCES ARE GIVEN IN MILES,
TIME IS FOR ROUND TRIP IN MINUTES.

TABLE B-12 TRAVELLING DATA - NORTHSIDE TO BEVERLY DUMP

BEVERLY DUMP LOCATION X=3.88, Y=2.40

ROUTE	LOCATION		L-METRIC DISTANCE	TRUE DISTANCE	TRAVELLING TIME
	X	Y			
18	-0.10	4.00	5.45	5.70	52.00
19	0.65	3.68	4.33	4.50	44.00
20	1.20	2.97	3.32	3.90	37.00
21	2.18	2.78	1.96	2.00	32.00
22	1.74	2.15	2.64	2.90	36.00
23	0.38	1.33	4.90	4.70	41.00
24	0.19	3.10	4.33	4.30	40.00
25	-0.81	0.00	7.22	6.80	55.00
26	-0.87	0.60	6.68	6.40	52.00
27	-0.27	0.73	5.78	5.40	50.00
28	1.00	4.11	4.55	4.60	47.00
29	2.31	3.54	3.13	4.30	42.00
30	-1.52	0.32	7.47	7.60	57.00
31	-1.30	1.11	6.43	6.40	52.00
32	-0.27	1.28	5.34	5.40	45.00
33	-0.27	2.15	4.52	4.60	44.00
34	0.27	2.15	3.92	3.80	43.00
35	0.00	2.70	4.17	4.40	42.00
48	1.28	0.73	4.44	4.50	40.00
52	3.27	2.37	0.54	1.00	29.00
58	2.04	7.14	4.44	5.50	46.00
59	0.54	5.64	6.00	5.90	53.00
12	-1.80	1.60	6.38	6.30	50.00
13	-0.81	2.23	4.80	5.10	45.00
14	-2.86	4.33	8.61	8.20	60.00
15	-2.61	3.73	7.69	7.80	60.00
16	-1.36	4.33	7.09	6.90	58.00
17	-1.36	3.73	6.43	6.60	58.00

DISTANCES ARE GIVEN IN MILES,
TIME IS FOR ROUND TRIP IN MINUTES.

TABLE B-13 TRAVELLING DATA - NORTHSIDE TO TRANSFER STATION

TRANSFER STATION LOCATION X=-3.74, Y=2.04

ROUTE	LOCATION		L-METRIC DISTANCE	TRUE DISTANCE	TRAVELLING TIME
	X	Y			
1	-3.46	-1.14	3.32	3.50	38.00
5	-3.24	0.62	1.99	2.20	32.00
6	-2.50	0.84	2.50	2.30	34.00
7	-3.00	1.41	1.44	1.90	30.00
8	-3.08	2.12	0.95	1.30	26.00
9	-3.84	3.08	0.95	1.20	24.00
10	-2.78	3.05	2.18	1.90	30.00
11	-2.37	2.23	1.71	1.80	32.00

DISTANCES ARE GIVEN IN MILES,
TIME IS FOR ROUND TRIP IN MINUTES.

APPENDIX C

THE REDUCED DATA

The raw data as obtained was generalized by the use of fitting functions as described previously. In this appendix, graphs are shown of the raw data including the curves of the fitting functions.

The modeling functions were then obtained from the generalized fitting functions.

To summarize the steps involved; firstly the raw data time series of the actual weight per household-week are given. The trend equation was then obtained for this time series by the use of the 52-week moving average. The normalized weight per household-week time series was obtained by division of the actual weight per household-week by the equation representing the trend line. Finally the normalized weight per household-week time curves were fitted to a 26 term Fourier series with a period of 52 weeks.

The actual density as collected was similarly correlated to the actual weight per household-week. The correlation function in this case was found to be linear and is also shown with the actual data.

Finally the travelling times between the routes and the existing disposal areas were correlated with the L-metric length. The actual data and fitted linear functions are also given.

TABLE C-1
FOURIER COEFFICIENTS $c_j(i)$

Route

j	1	3	7	30	31	42	47
0	1.0000	0.9996	1.0000	0.9999	0.9999	0.999	1.0000
1	0.3572	0.2968	0.2727	0.0947	0.0673	0.1910	0.2407
2	0.0998	0.0966	0.0736	0.0552	0.0271	0.0861	0.0752
3	0.0905	0.1118	0.1057	0.0415	0.0543	0.0793	0.1024
4	0.0069	0.0129	0.0258	0.0269	0.0259	0.0378	0.0327
5	0.0653	0.0370	0.0378	0.0151	0.0222	0.0338	0.0340
6	0.0597	0.0398	0.0291	0.0302	0.0224	0.0304	0.0298
7	0.0191	0.0218	0.0199	0.0117	0.0217	0.0164	0.0167
8	0.0284	0.0316	0.0290	0.0140	0.0093	0.0098	0.0223
9	0.0266	0.0170	0.0151	0.0253	0.0118	0.0093	0.0291
10	0.0218	0.0205	0.0237	0.0105	0.0102	0.0092	0.0107
11	0.0126	0.0197	0.0142	0.0047	0.0044	0.0163	0.0055
12	0.0090	0.0098	0.0118	0.0267	0.0291	0.0083	0.0098
13	0.0206	0.0199	0.0203	0.0043	0.0030	0.0059	0.0113
14	0.0156	0.0115	0.0149	0.0157	0.0120	0.0045	0.0098
15	0.0094	0.0051	0.0093	0.0071	0.0086	0.0074	0.0009
16	0.0088	0.0133	0.0096	0.0028	0.0037	0.0082	0.0156
17	0.0055	0.0150	0.0104	0.0044	0.0097	0.0218	0.0130
18	0.0119	0.0082	0.0045	0.0093	0.0141	0.0059	0.0170
19	0.0126	0.0027	0.0139	0.0042	0.0114	0.0124	0.0111
20	0.0064	0.0077	0.0089	0.0080	0.0067	0.0120	0.0170
21	0.0140	0.0080	0.0169	0.0018	0.0084	0.0078	0.0151
22	0.0169	0.0035	0.0111	0.0100	0.0049	0.0122	0.0016
23	0.0060	0.0077	0.0138	0.0059	0.0003	0.0106	0.0051
24	0.0103	0.0080	0.0094	0.0130	0.0114	0.0203	0.0039
25	0.0196	0.0118	0.0178	0.0120	0.0095	0.0195	0.0269
26	0.0080	0.0087	0.0135	0.0007	0.0048	0.0137	0.0171

TABLE C-2

FOURIER PHASE ANGLE CONSTANTS $\phi_j(i)$

[illegible]

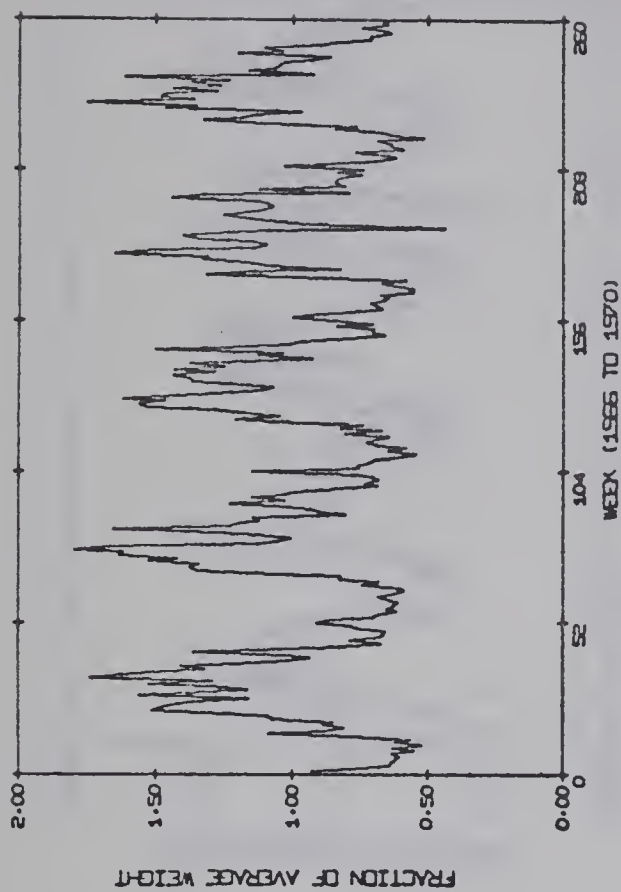


FIGURE C-1-2 ROUTE NO. 1 - NORMALIZED WEIGHT PER HOUSEHOLD

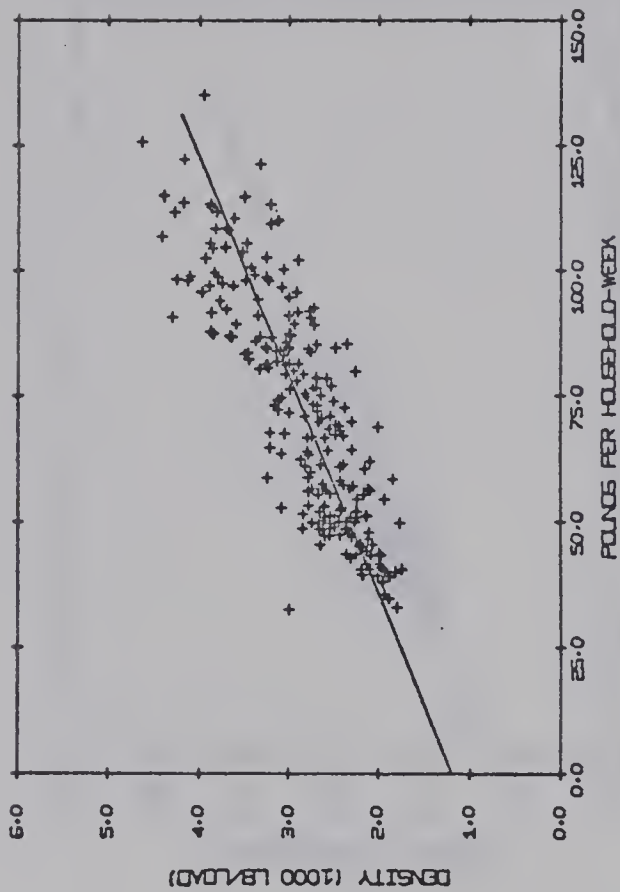


FIGURE C-1-4 ROUTE NO. 1 - DENSITY CORRELATION

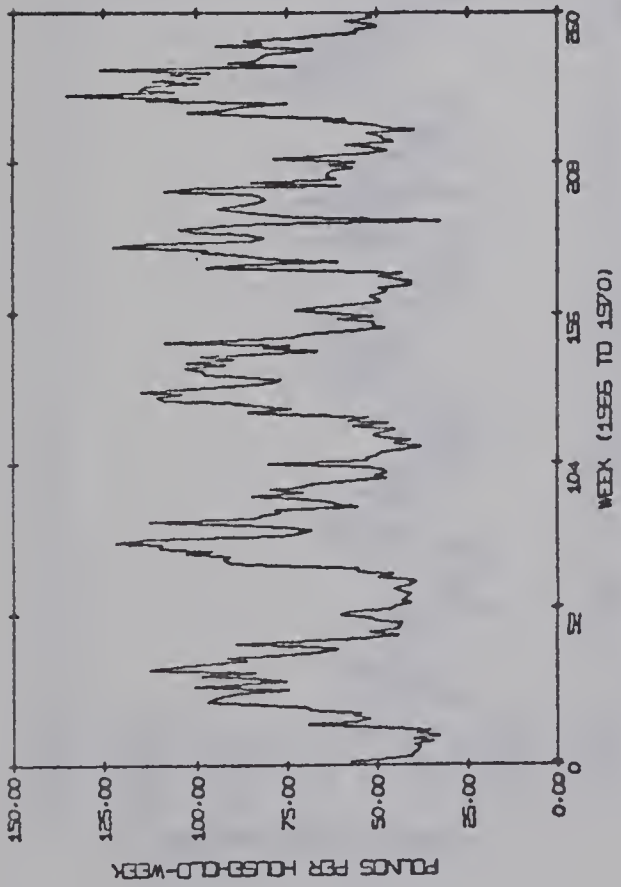


FIGURE C-1-1 ROUTE NO. 1 - ACTUAL WEIGHT PER HOUSEHOLD

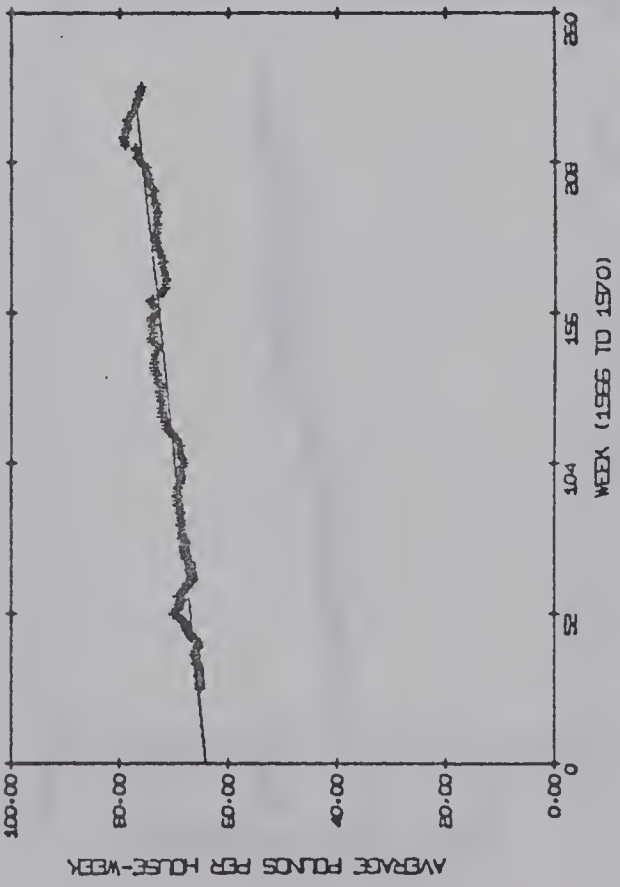


FIGURE C-1-3 ROUTE NO. 1 - 52-WEEK MOVING AVERAGE

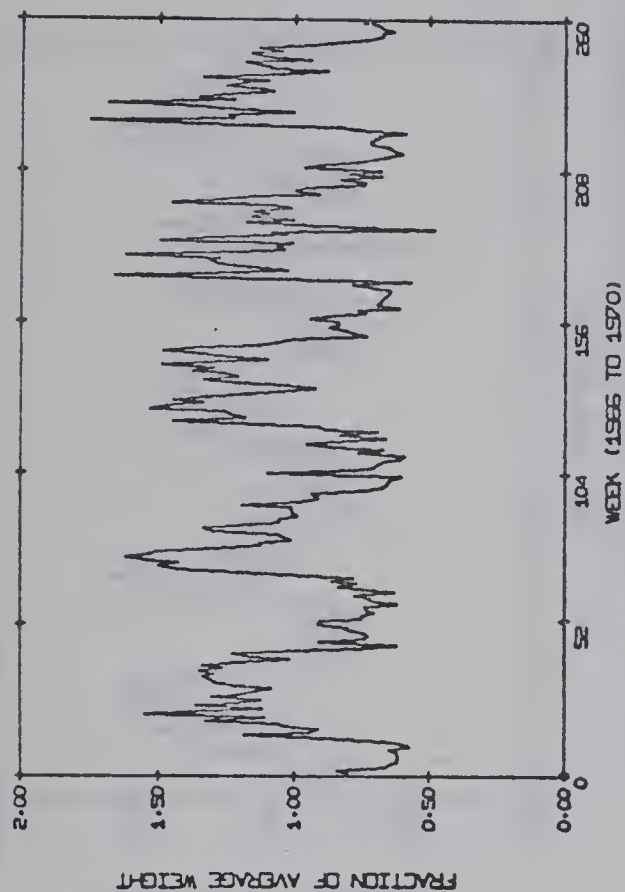


FIGURE C-2-1 ROUTE NO. 3 - ACTUAL WEIGHT PER HOUSEHOLD

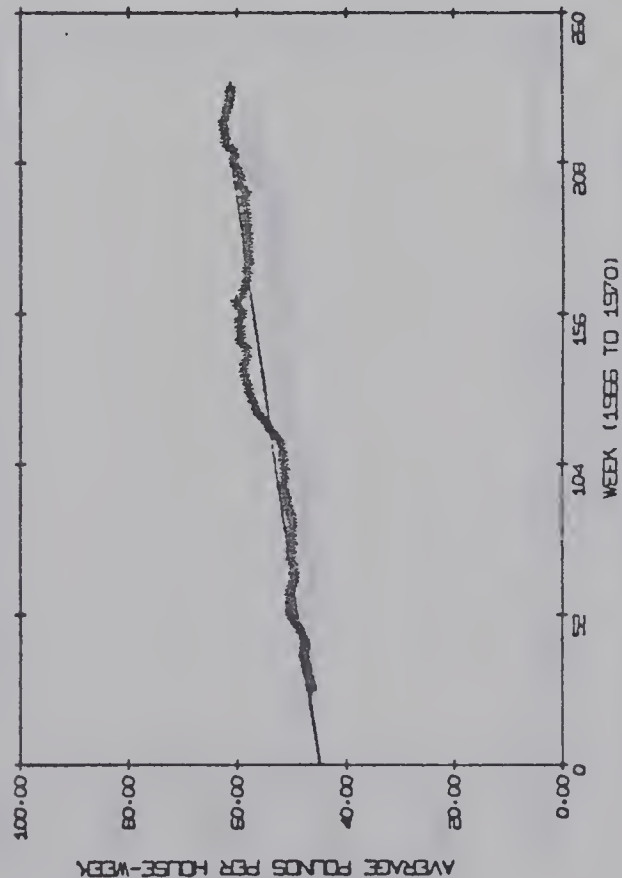


FIGURE C-2-2 ROUTE NO. 3 - 52-WEEK MOVING AVERAGE

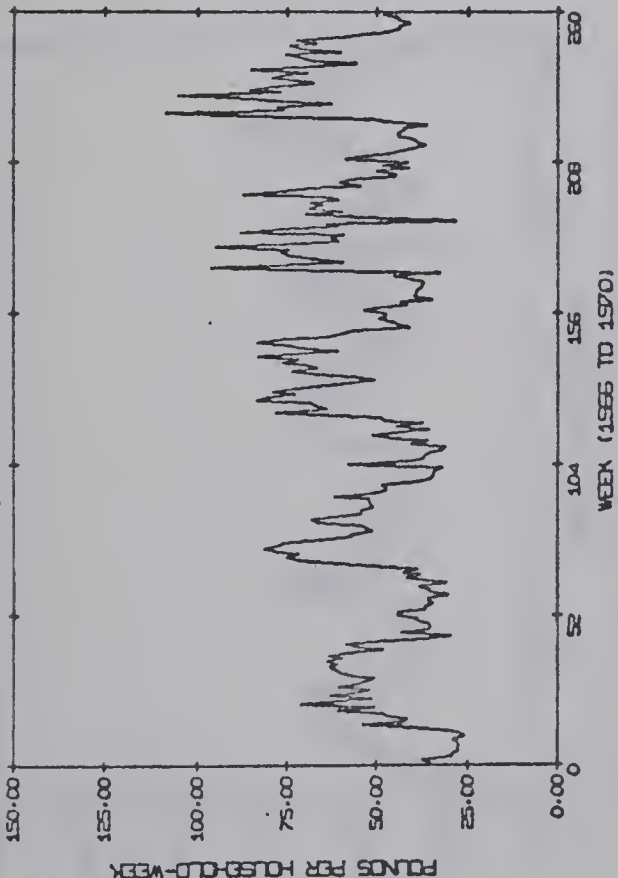


FIGURE C-2-3 ROUTE NO. 3 - NORMALIZED WEIGHT PER HOUSEHOLD

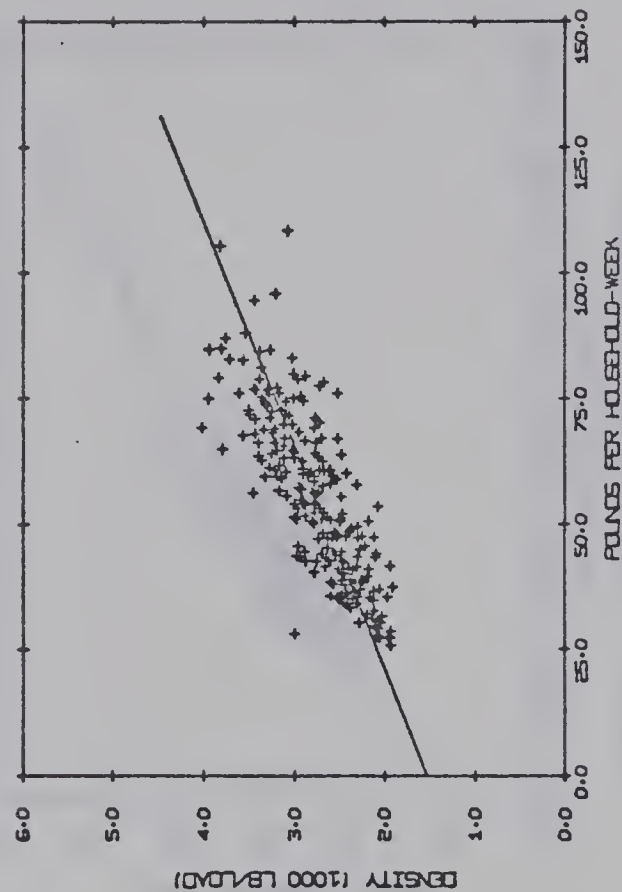


FIGURE C-2-4 ROUTE NO. 3 - DENSITY CORRELATION

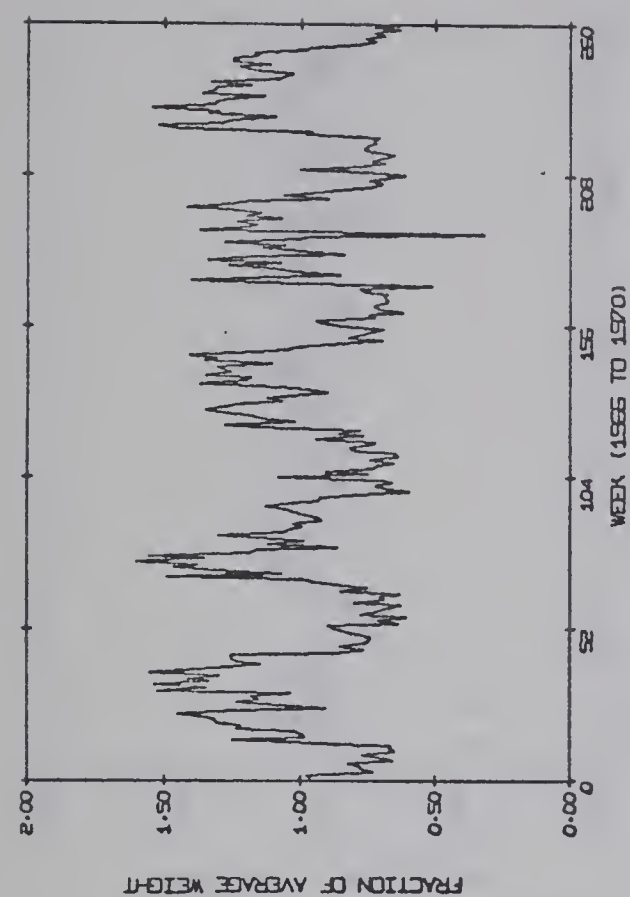


FIGURE C-3-2 ROUTE NO. 7 - NORMALIZED WEIGHT PER HOUSEHOLD

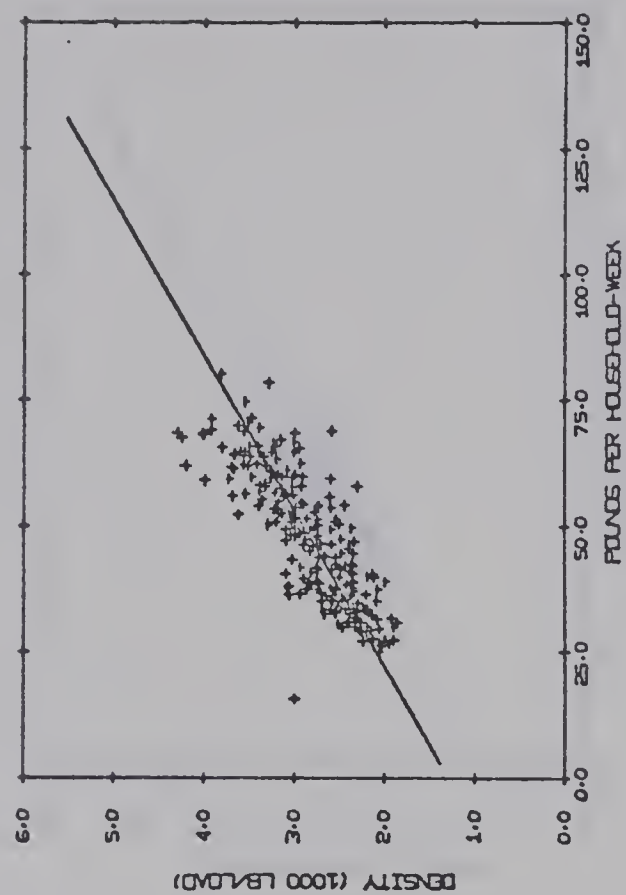


FIGURE C-3-4 ROUTE NO. 7 - DENSITY CORRELATION

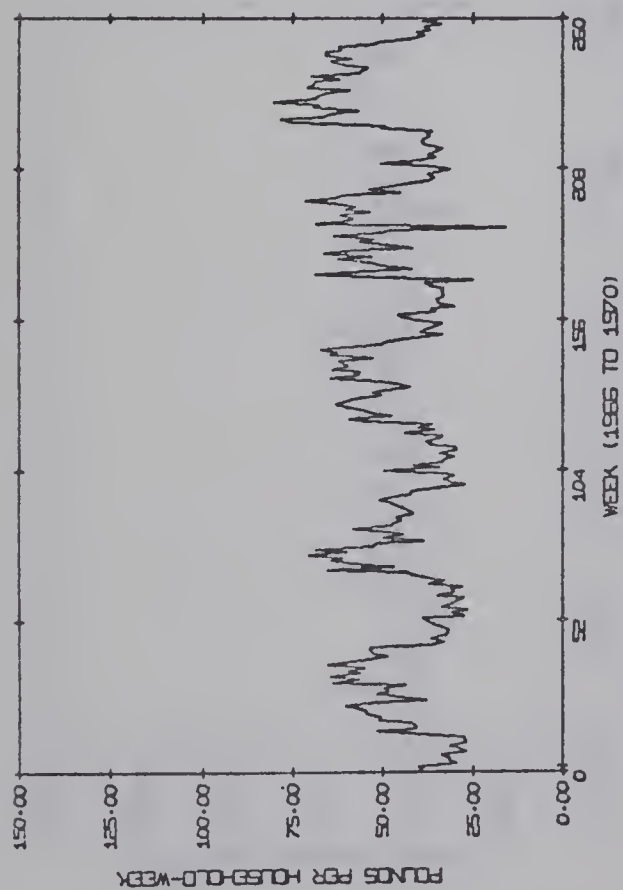


FIGURE C-3-1 ROUTE NO. 7 - ACTUAL WEIGHT PER HOUSEHOLD

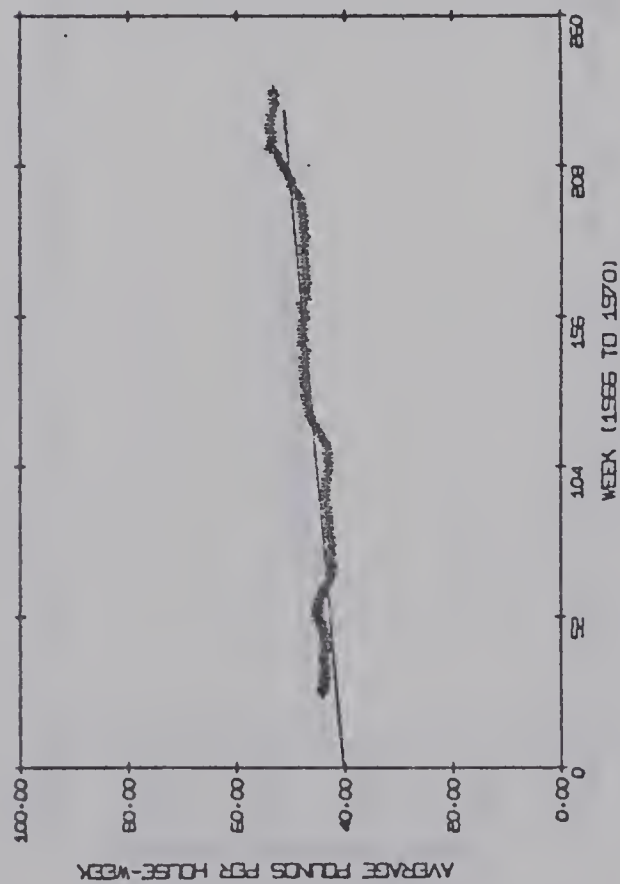


FIGURE C-3-3 ROUTE NO. 7 - 52-WEEK MOVING AVERAGE

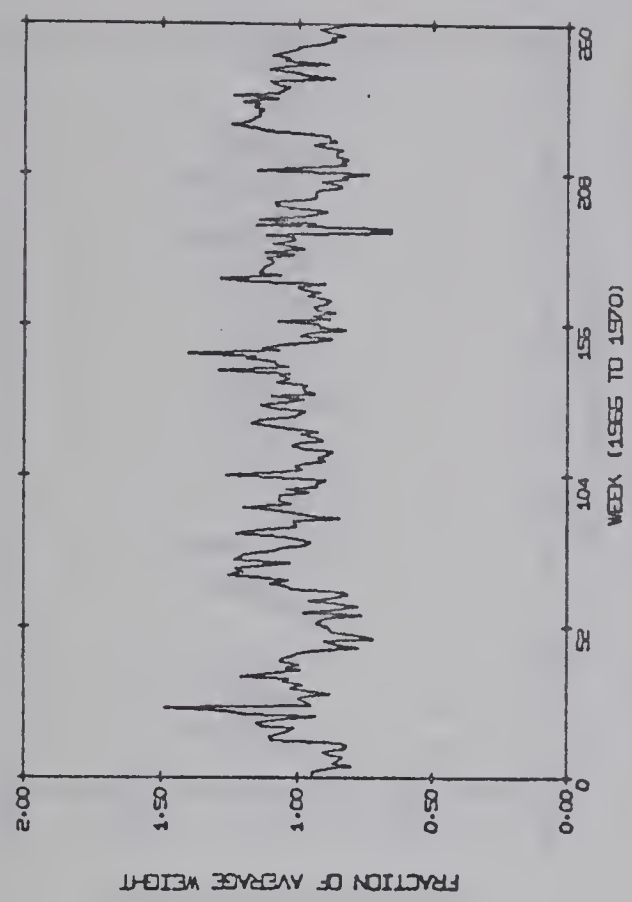


FIGURE C-4-2 ROUTE NO.30 - NORMALIZED WEIGHT PER HOUSEHOLD

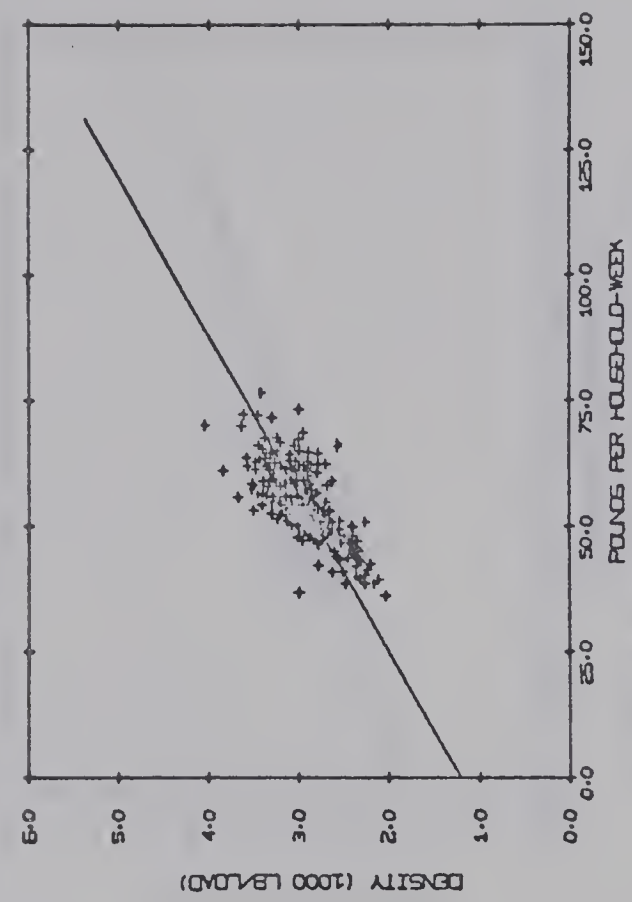


FIGURE C-4-4 ROUTE NO.30 - DENSITY CORRELATION

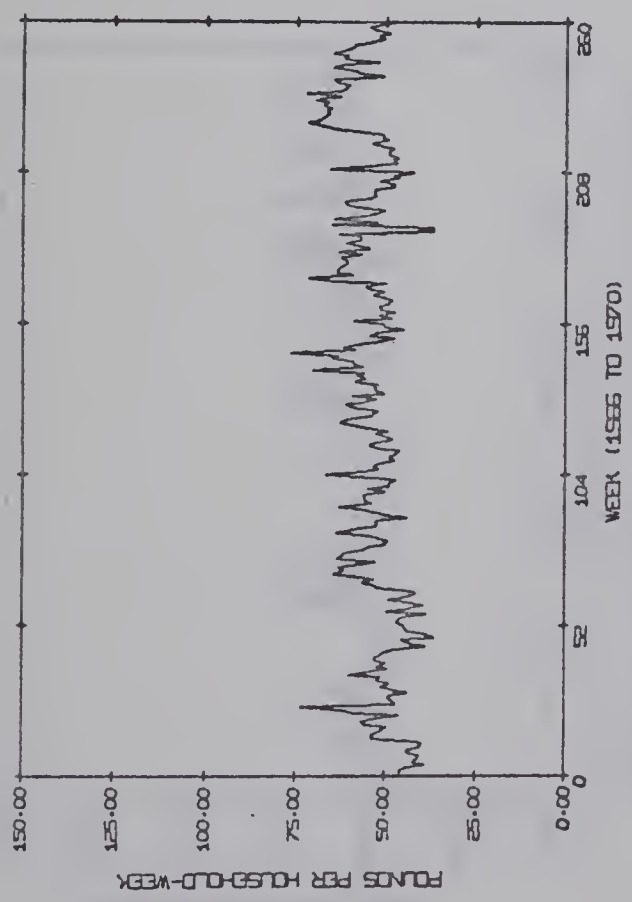


FIGURE C-4-1 ROUTE NO.30 - ACTUAL WEIGHT PER HOUSEHOLD

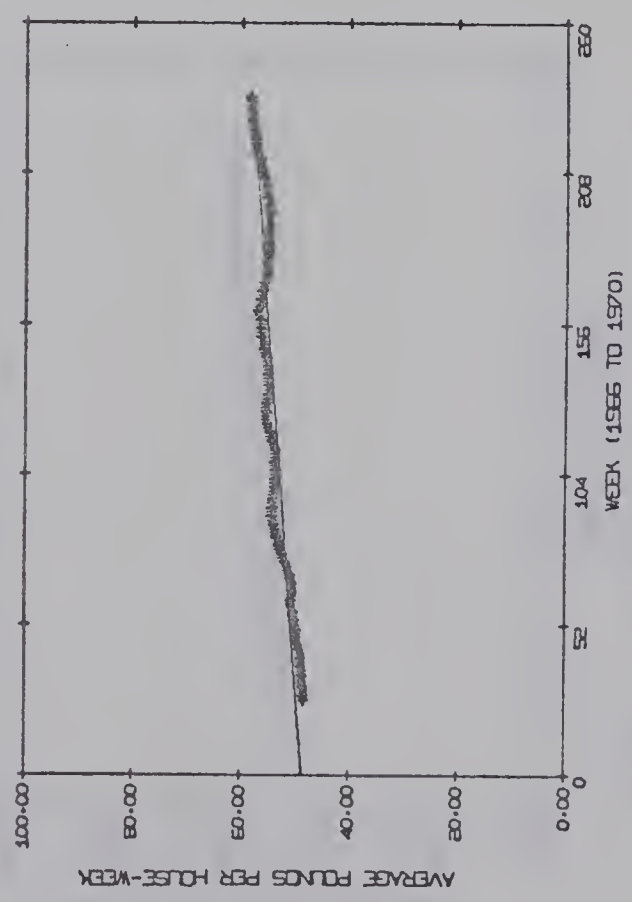


FIGURE C-4-3 ROUTE NO.30 - 52-WEEK MOVING AVERAGE

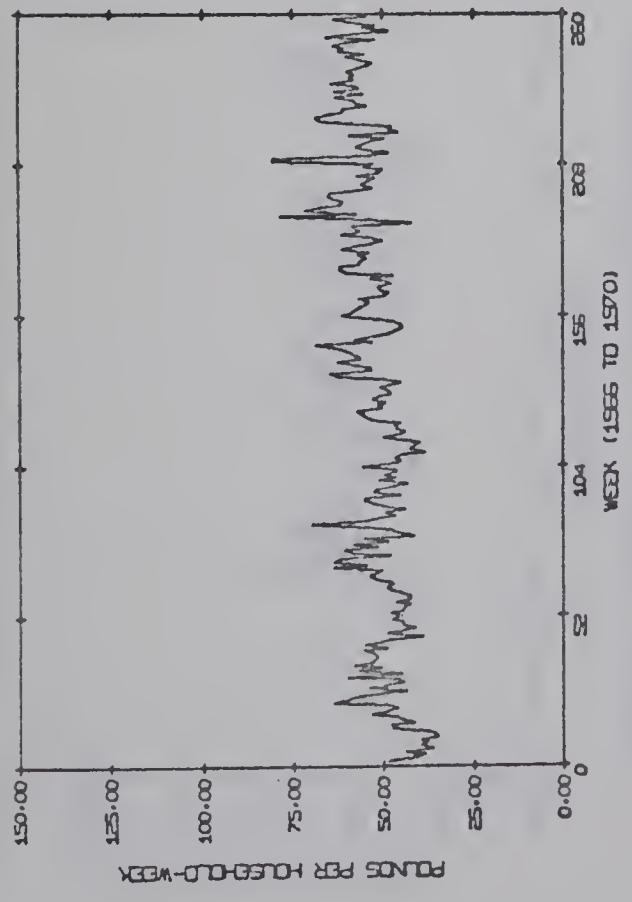


FIGURE C-S-1 ROUTE NO. 31 - ACTUAL WEIGHT PER HOUSEHOLD

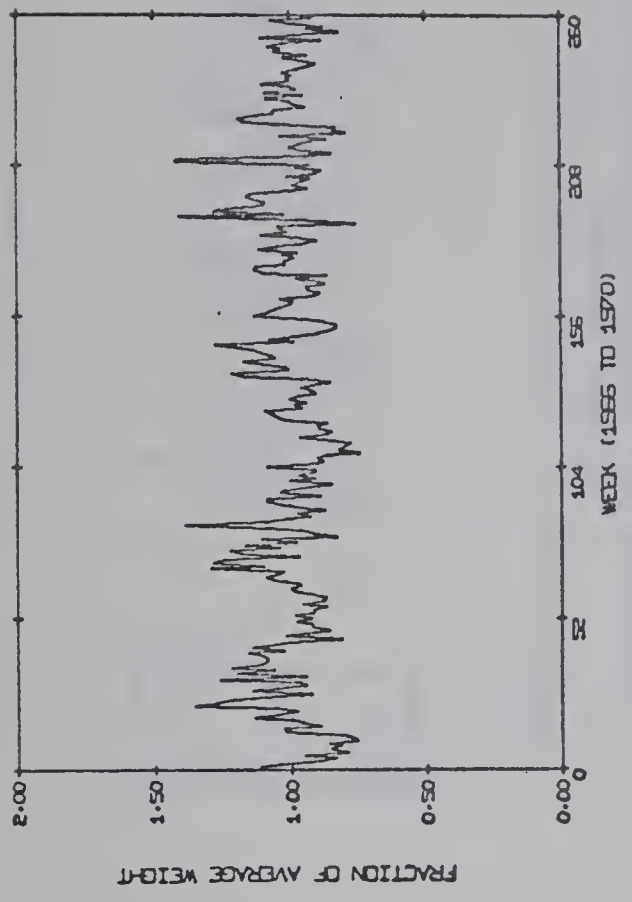


FIGURE C-S-2 ROUTE NO. 31 - NORMALIZED WEIGHT PER HOUSEHOLD

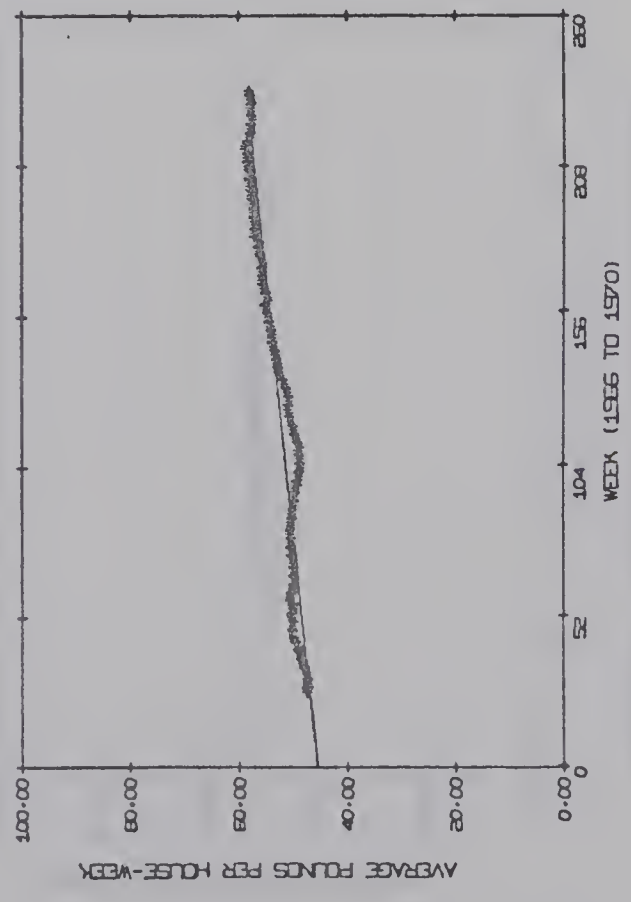


FIGURE C-S-3 ROUTE NO. 31 - 52-WEEK MOVING AVERAGE

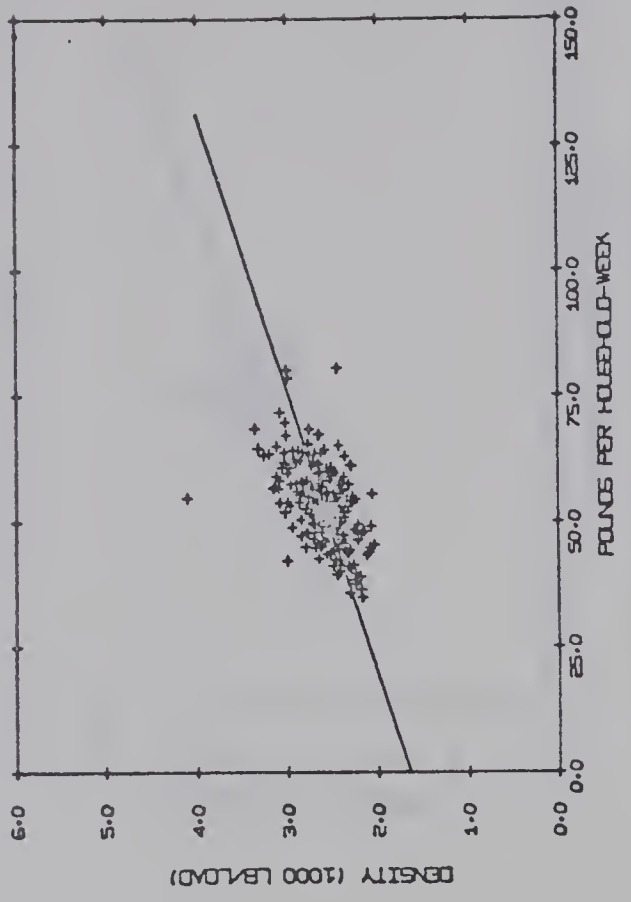


FIGURE C-S-4 ROUTE NO. 31 - DENSITY CORRELATION

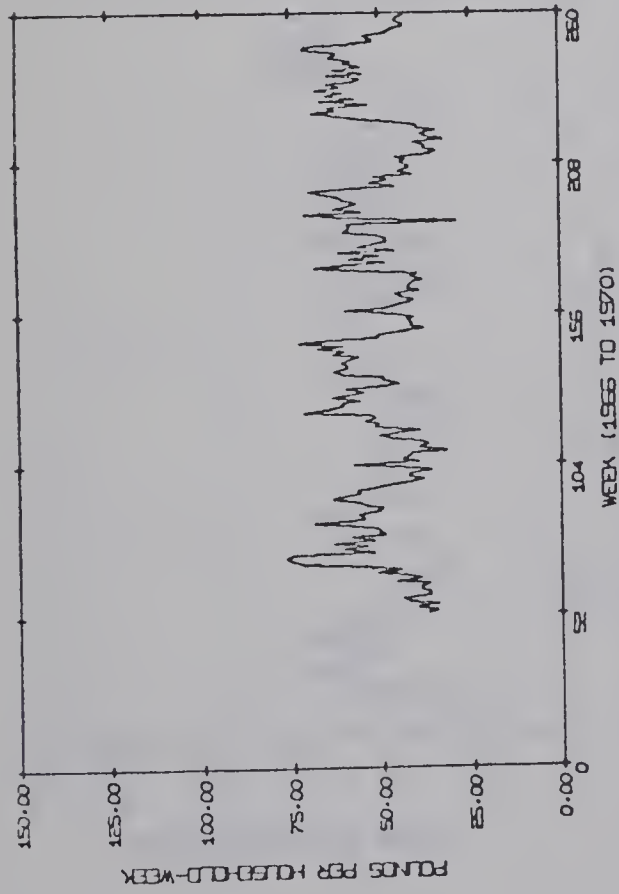


FIGURE C-6-1 ROUTE NO.42 - ACTUAL WEIGHT PER HOUSEHOLD

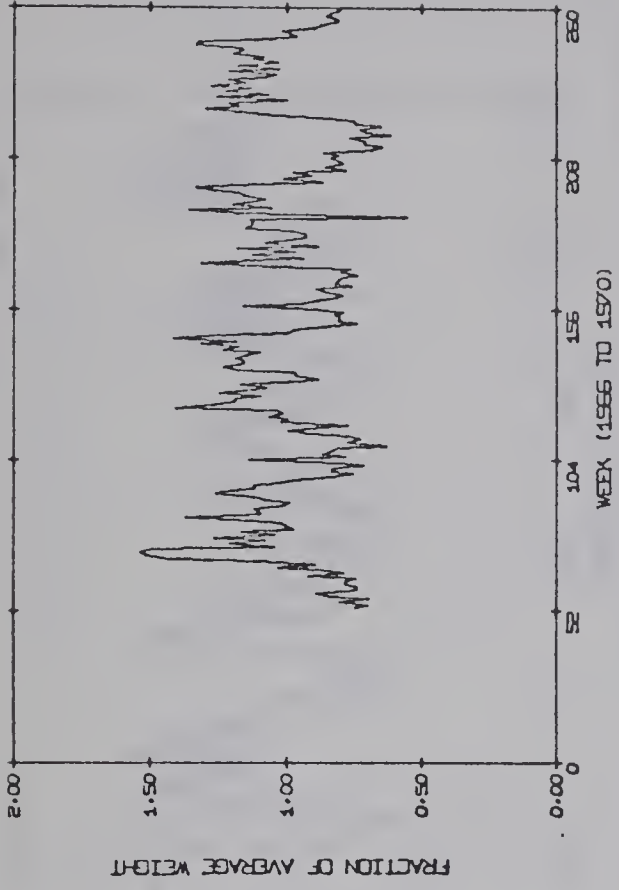


FIGURE C-6-2 ROUTE NO.42 - NORMALIZED WEIGHT PER HOUSEHOLD

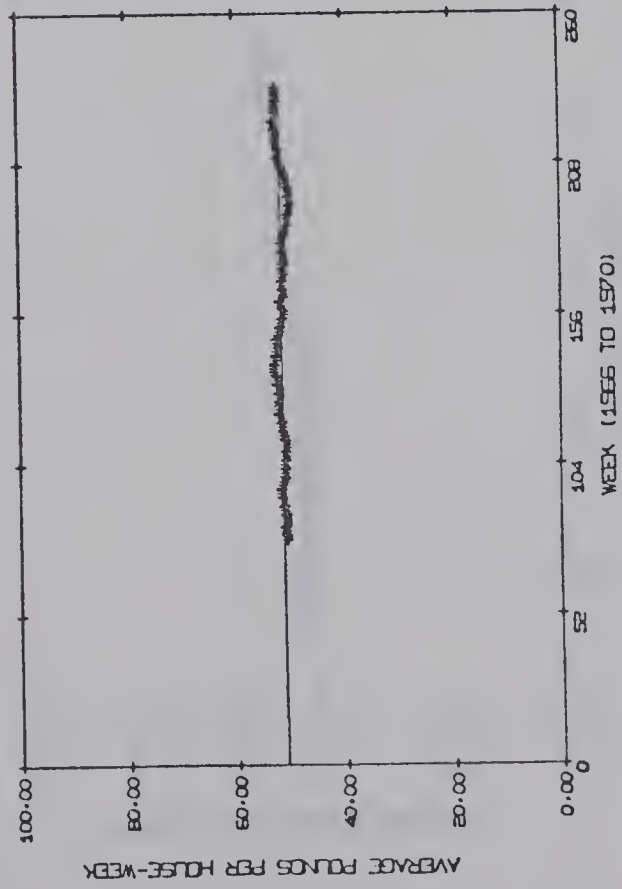


FIGURE C-6-3 ROUTE NO.42 - 52-WEEK MOVING AVERAGE

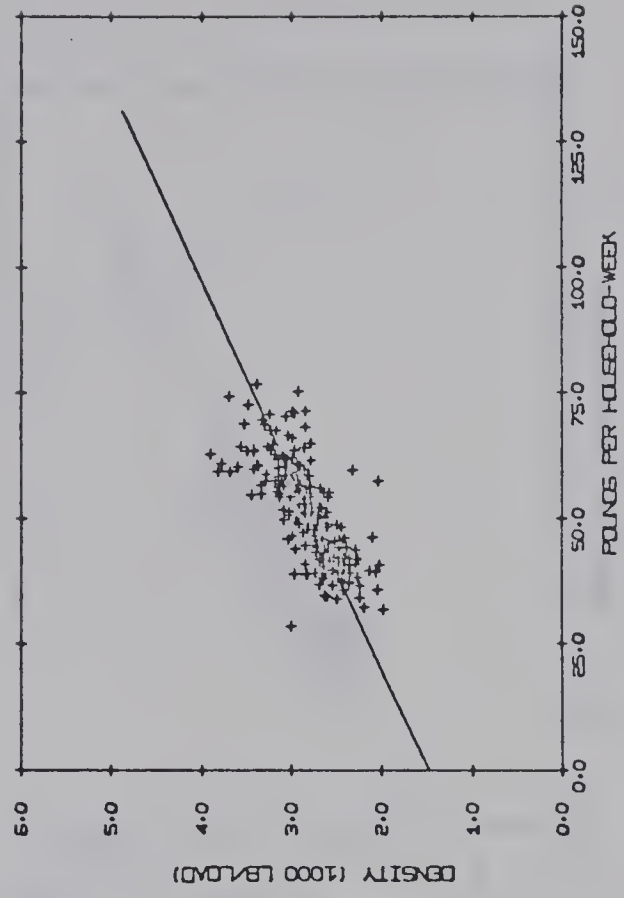


FIGURE C-6-4 ROUTE NO.42 - DENSITY CORRELATION

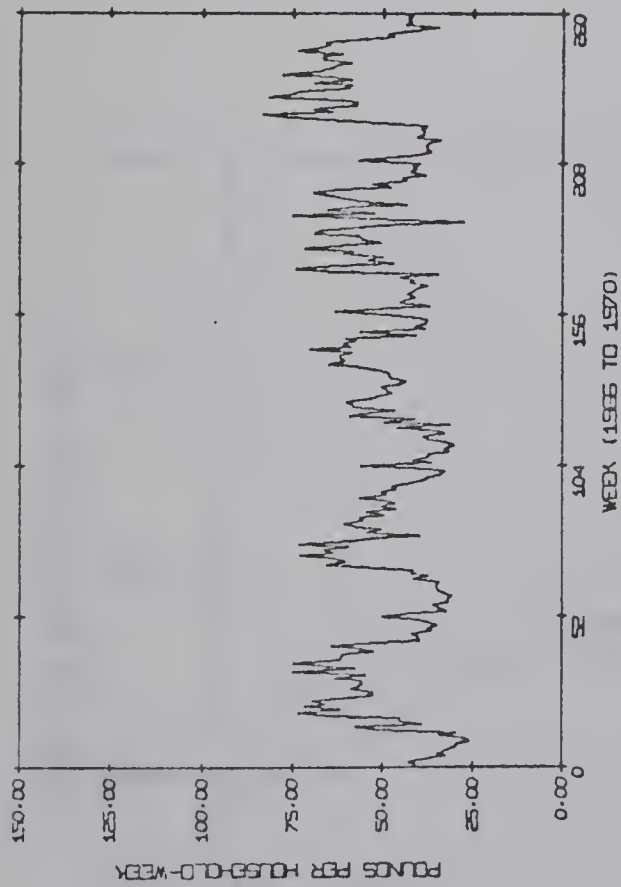


FIGURE C-7-1 ROUTE NO.47 - ACTUAL WEIGHT PER HOUSEHOLD

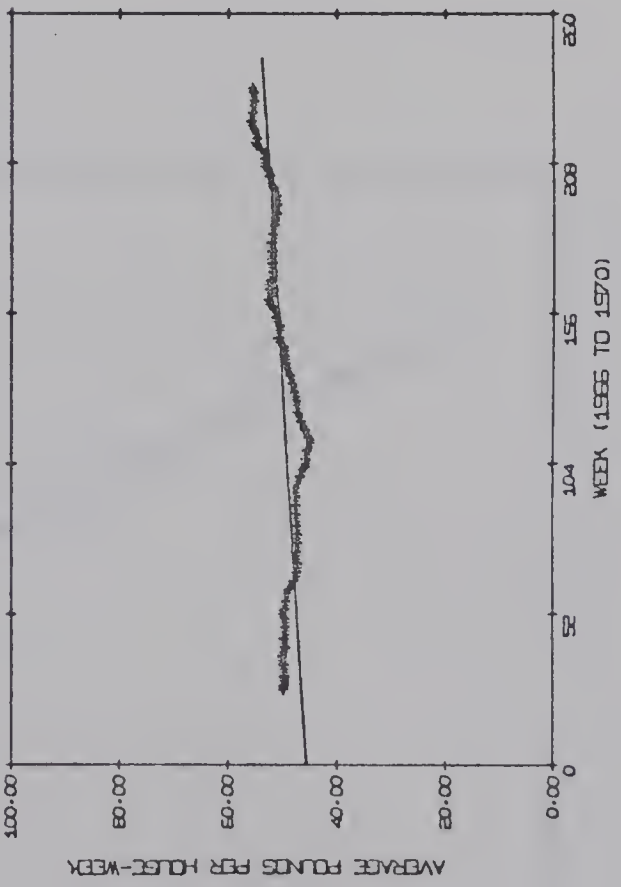


FIGURE C-7-3 ROUTE NO.47 - 52-WEEK MOVING AVERAGE

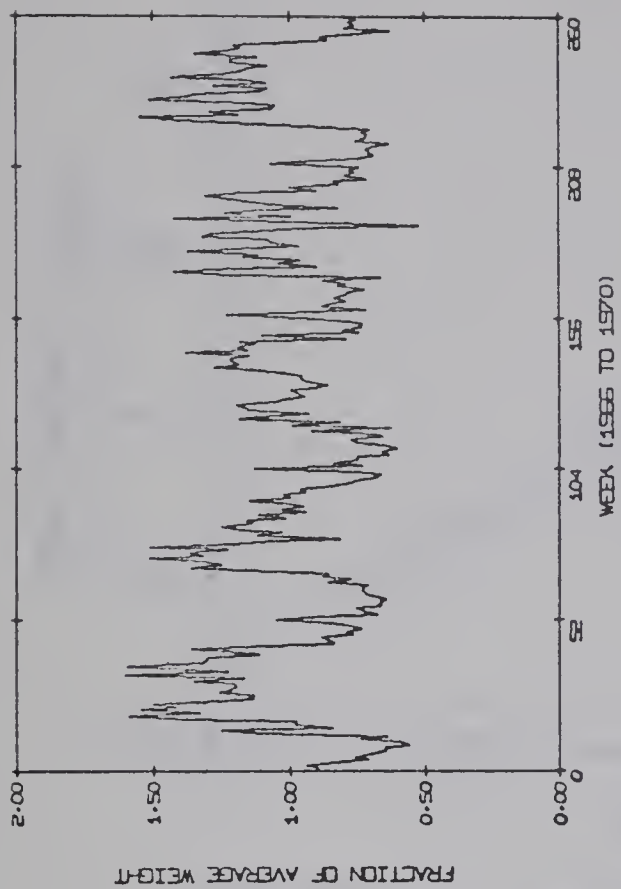


FIGURE C-7-2 ROUTE NO.47 - NORMALIZED WEIGHT PER HOUSEHOLD

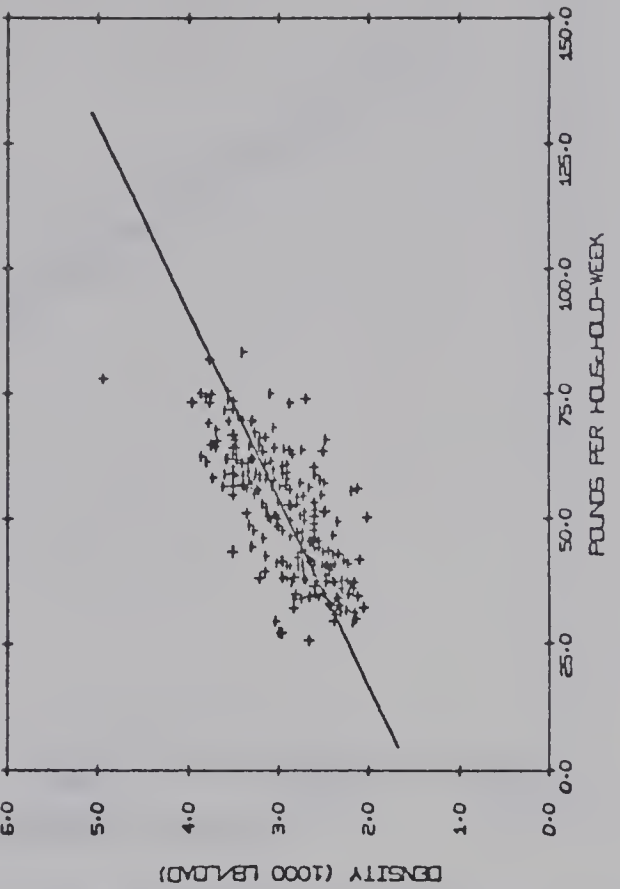


FIGURE C-7-4 ROUTE NO.47 - DENSITY CORRELATION

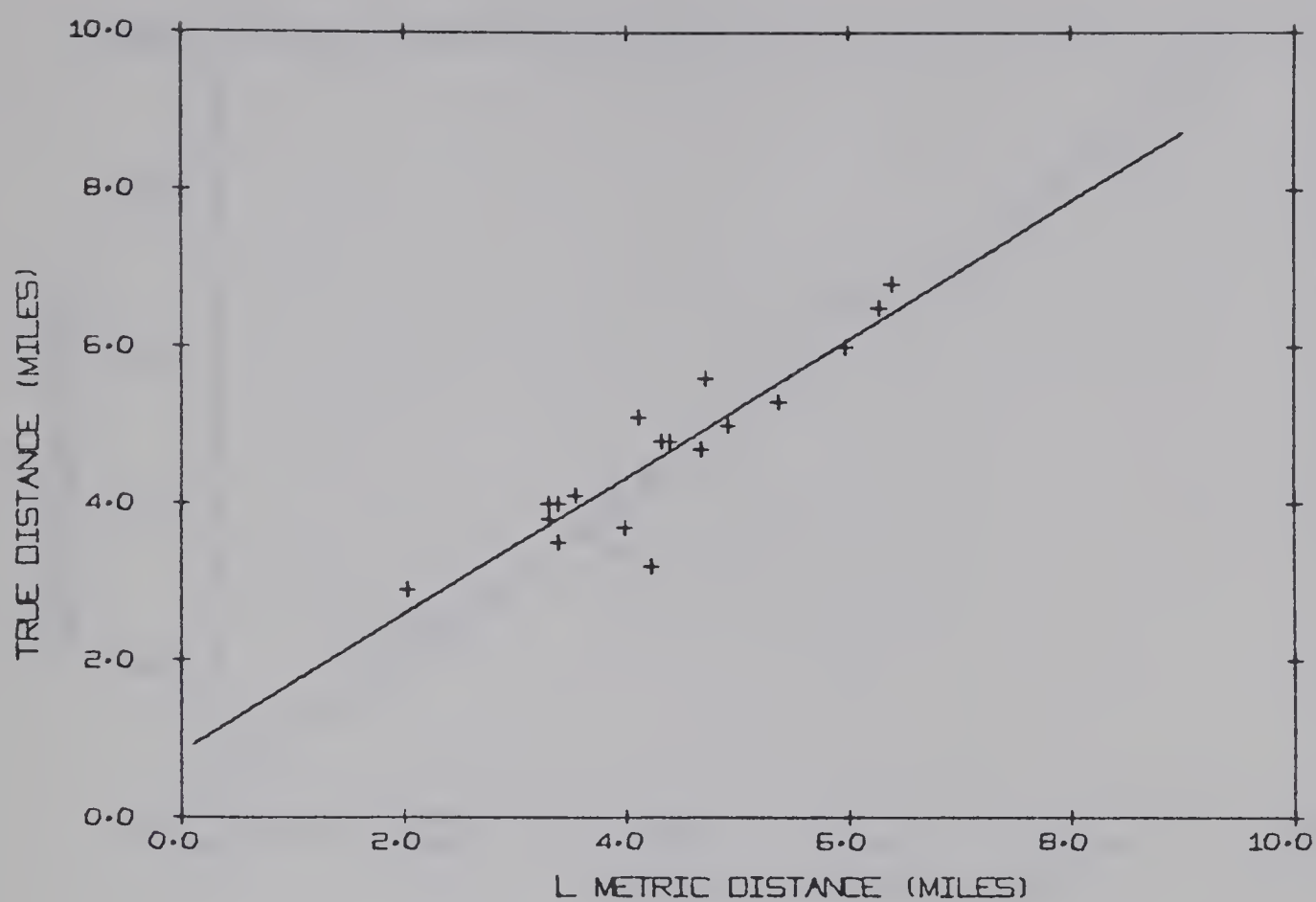


FIGURE C-8-1 TRUE DISTANCE - SOUTHSIDE TO SOUTHSIDE DUMP

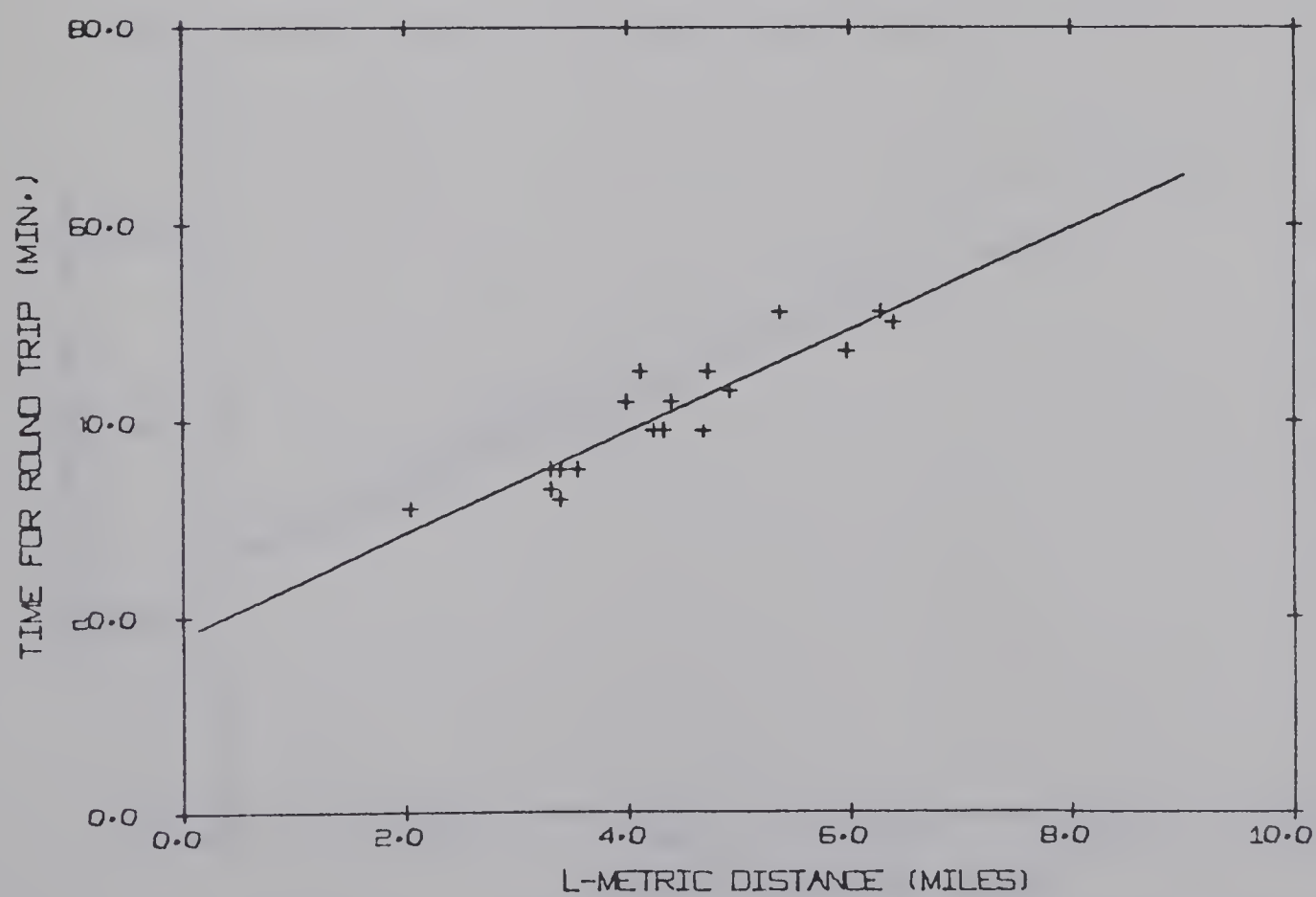


FIGURE C-8-2 TRAVELLING TIME - SOUTHSIDE TO SOUTHSIDE DUMP

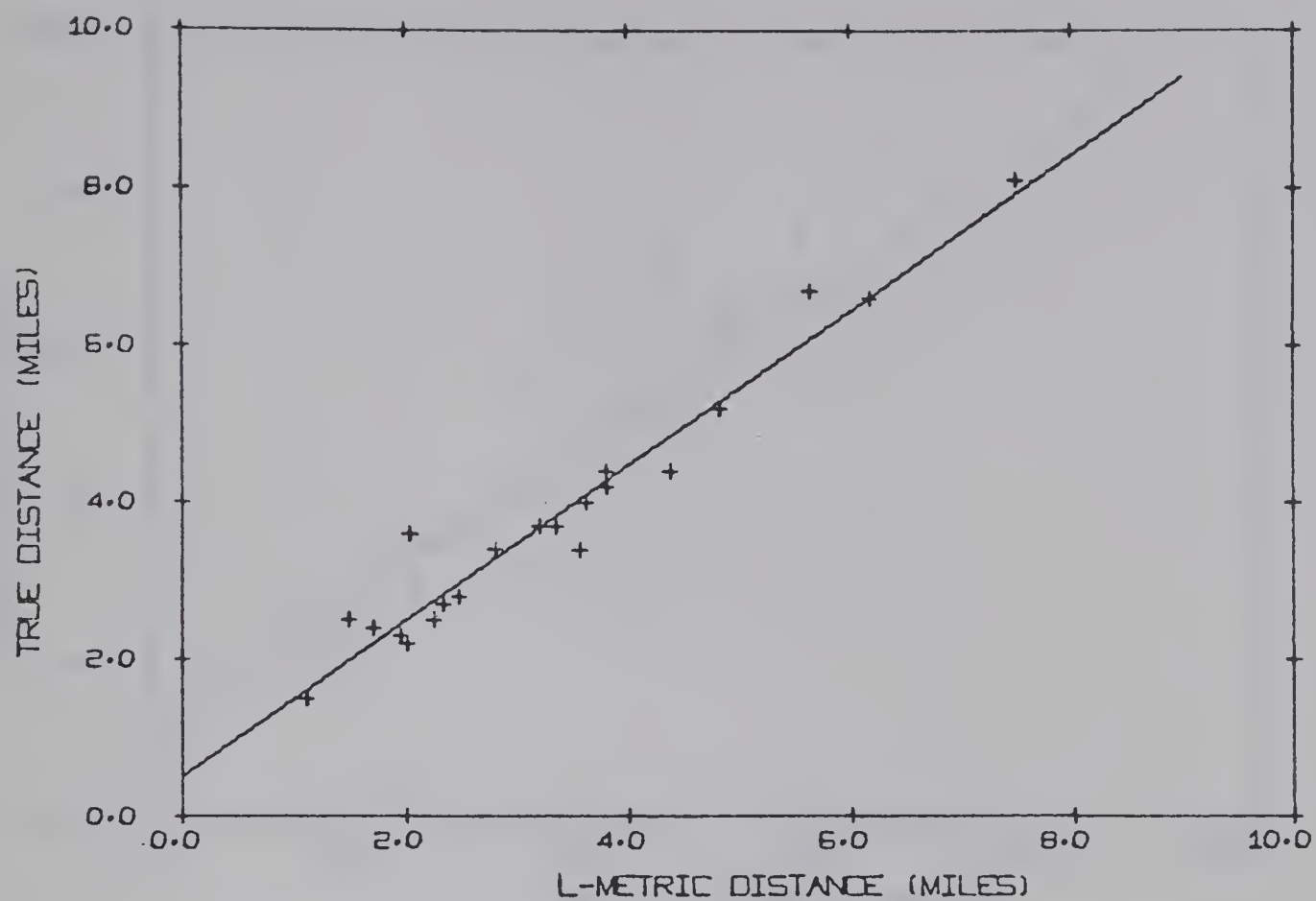


FIGURE C-9-1 TRUE DISTANCE - SOUTHSIDE TO INCINERATOR

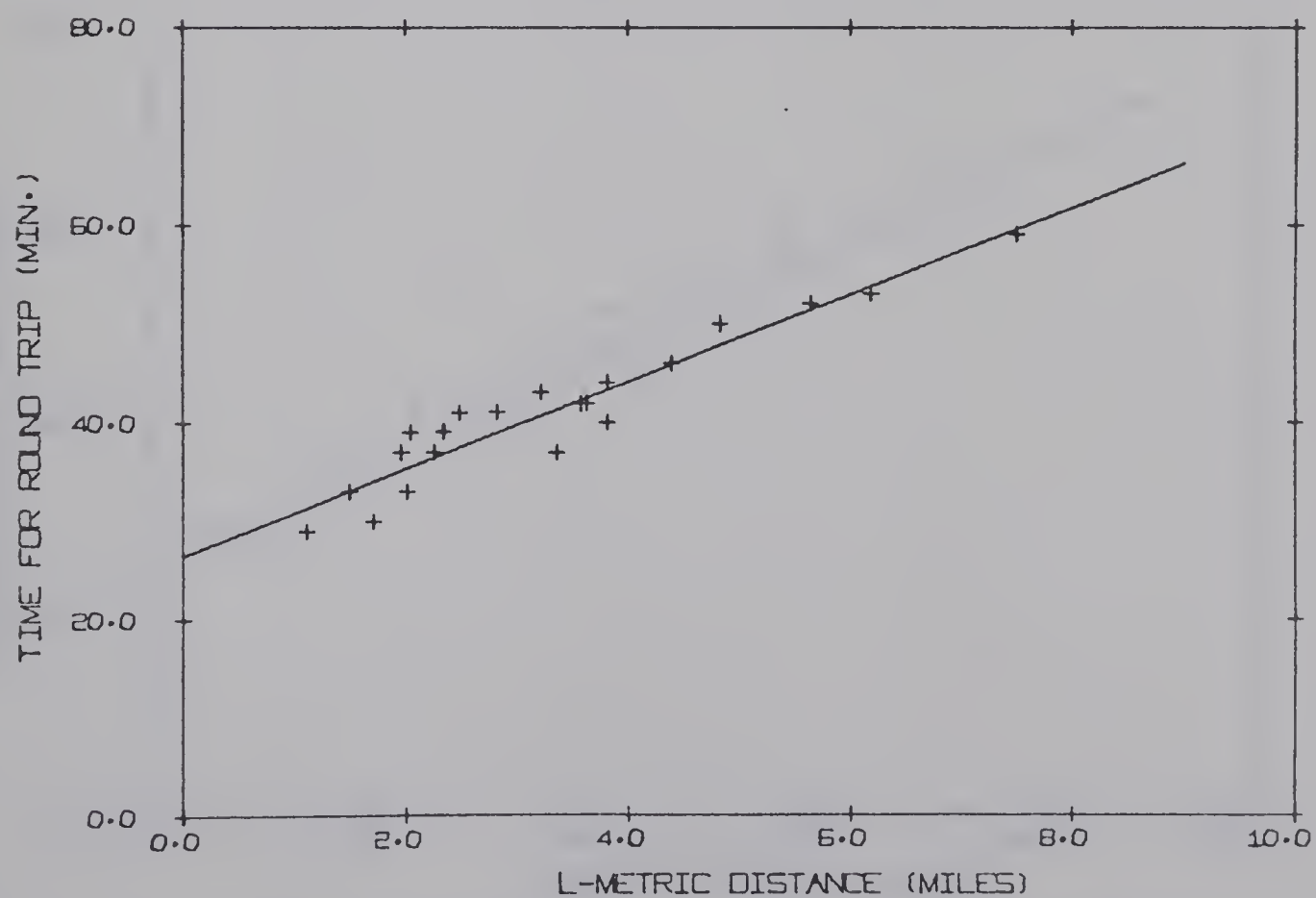


FIGURE C-9-2 TRAVELLING TIME - SOUTHSIDE TO INCINERATOR

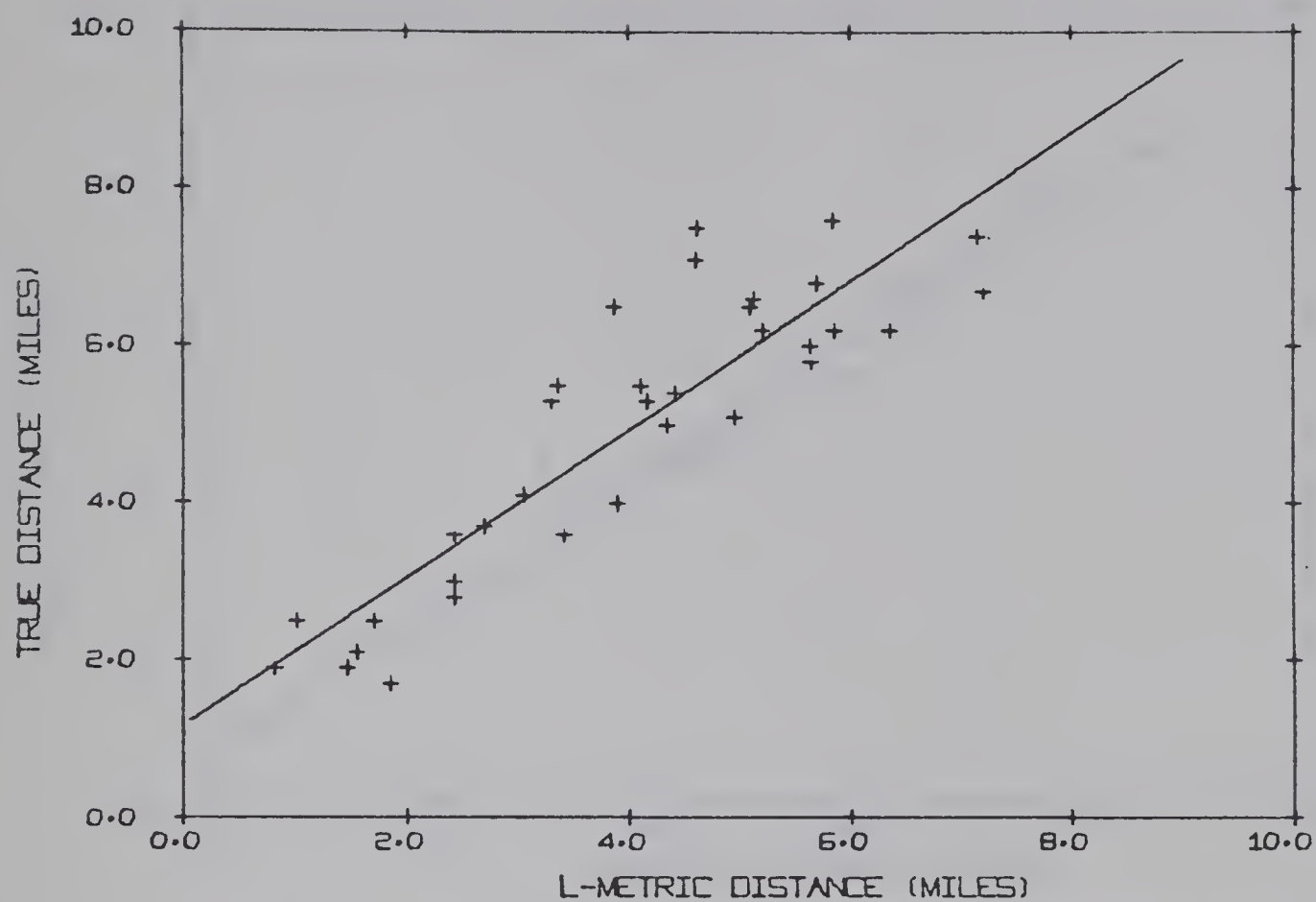


FIGURE C-10-1 TRUE DISTANCE - NORTHSIDE TO INCINERATOR

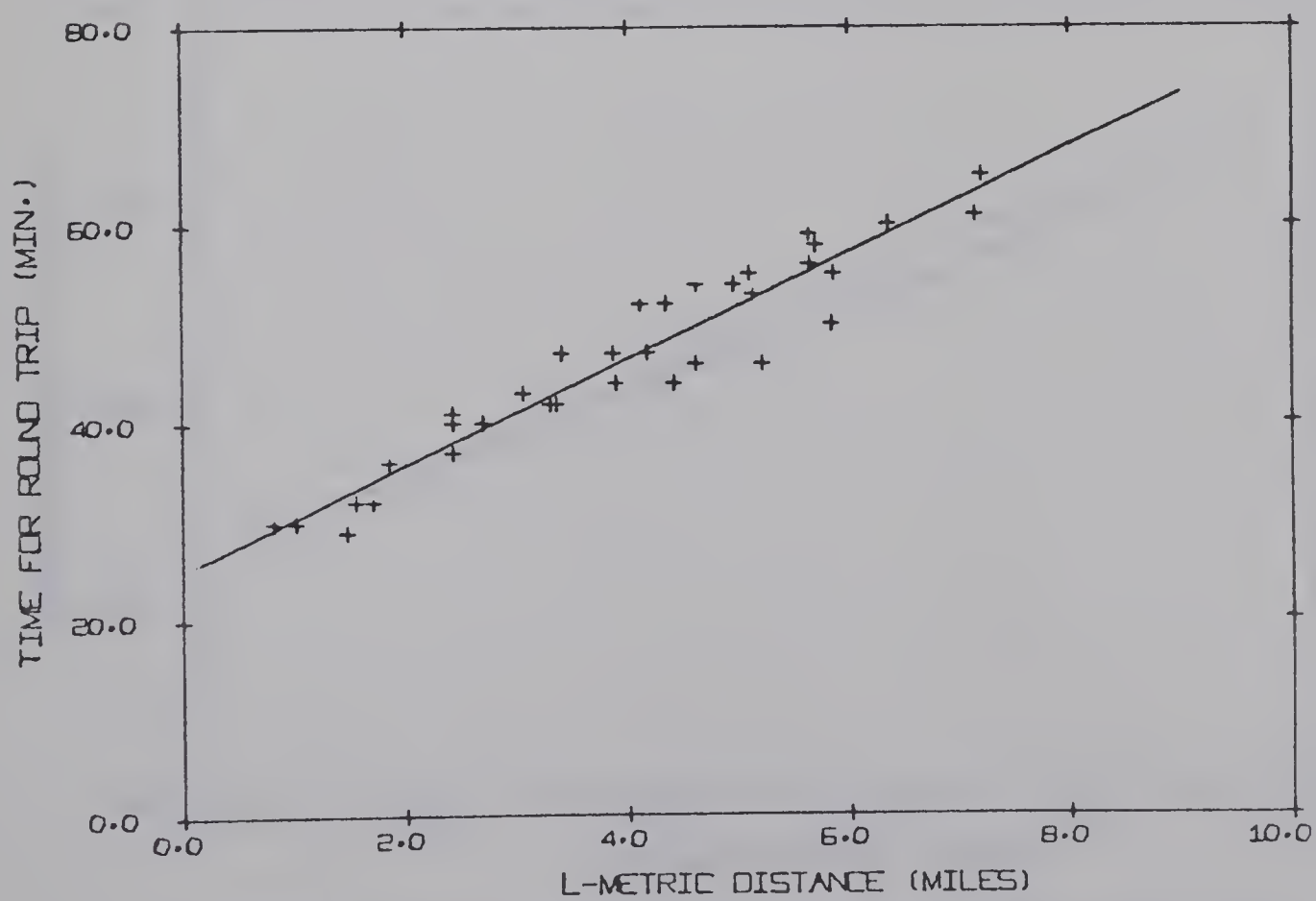


FIGURE C-10-2 TRAVELLING TIME- NORTHSIDE TO INCINERATOR

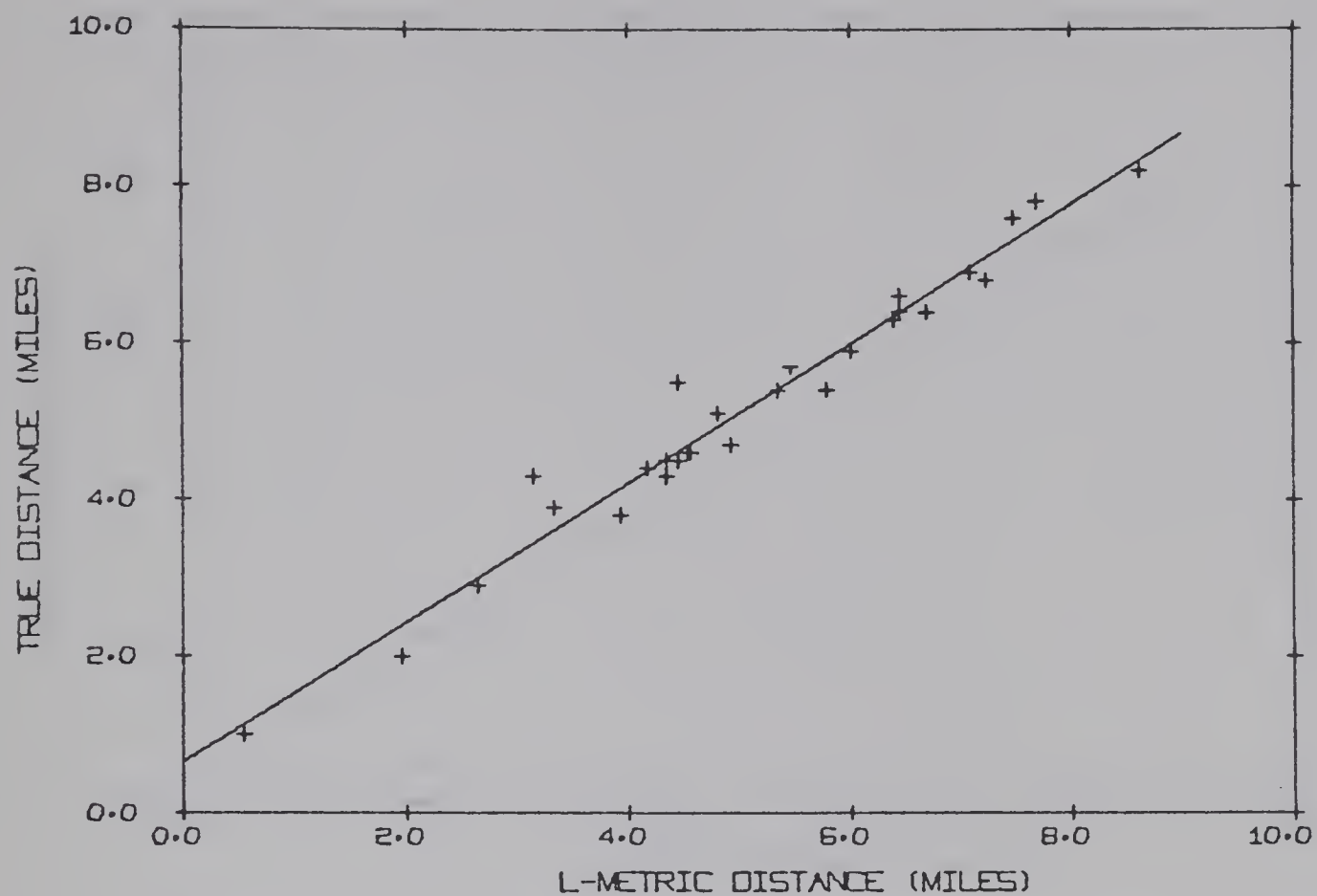


FIGURE C-11-1 TRUE DISTANCE - NORTHSIDE TO BEVERLY DUMP

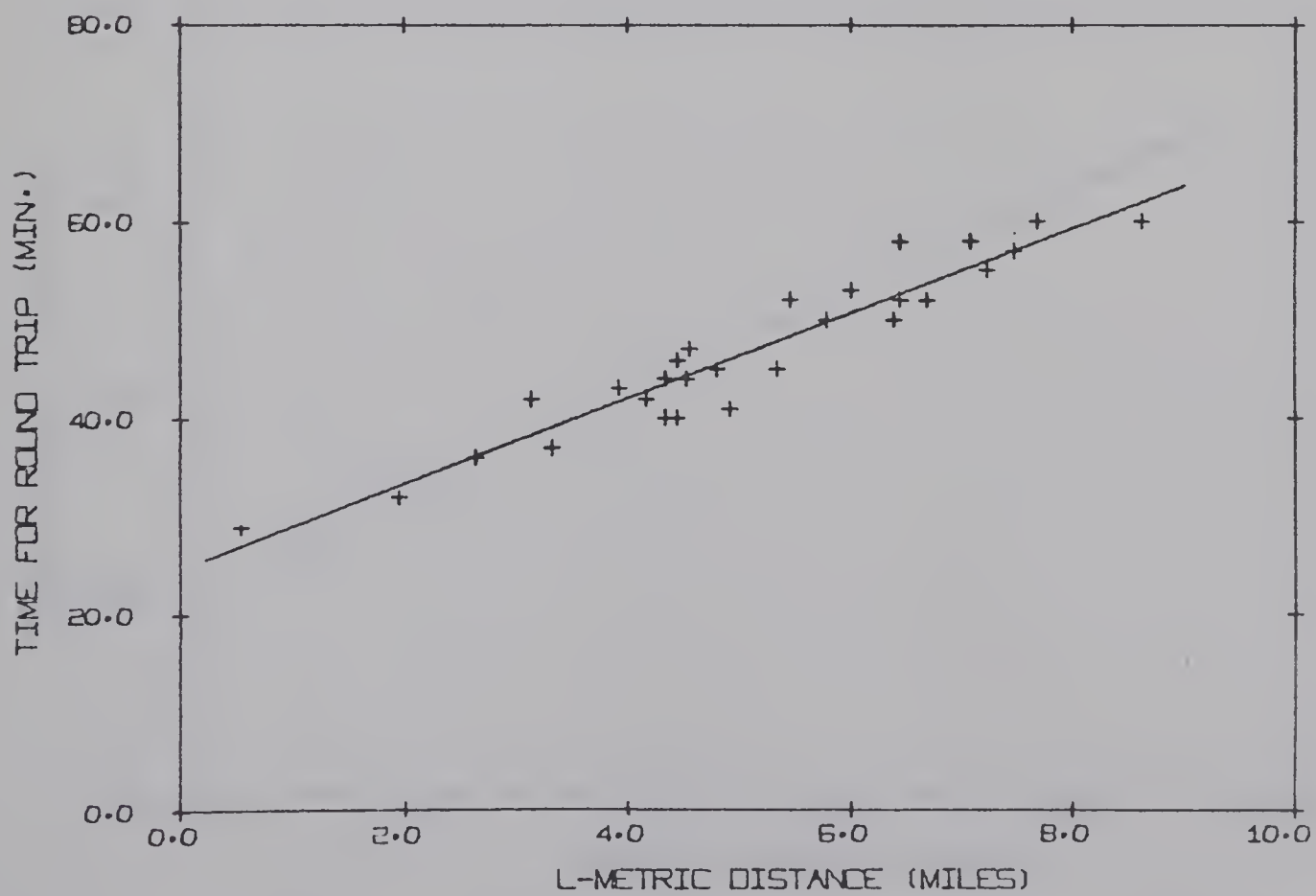


FIGURE C-11-2 TRAVELLING TIME- NORTHSIDE TO BEVERLY DUMP

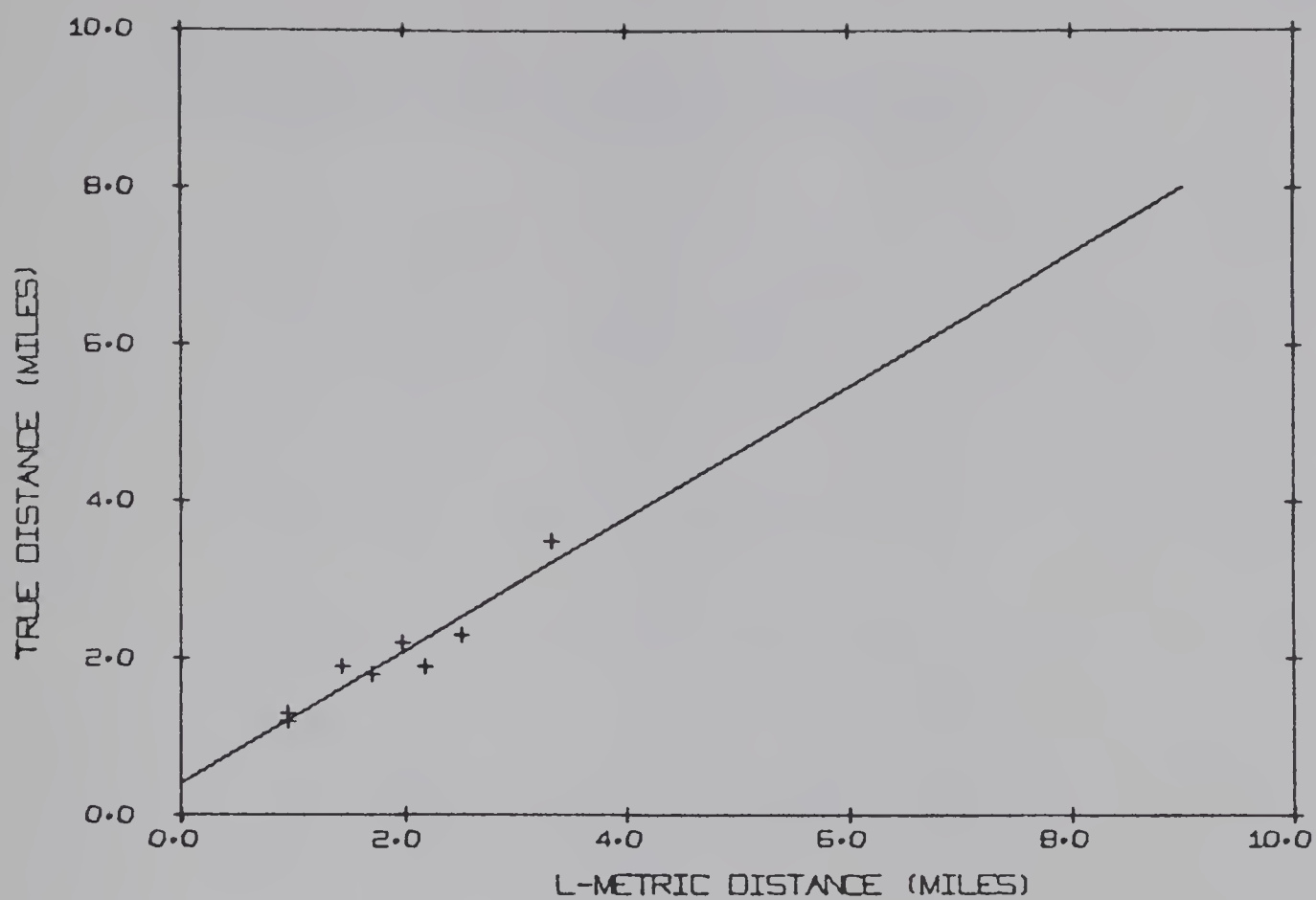


FIGURE C-12-1 TRUE DISTANCE - NORTHSIDE TO TRANSFER STATION

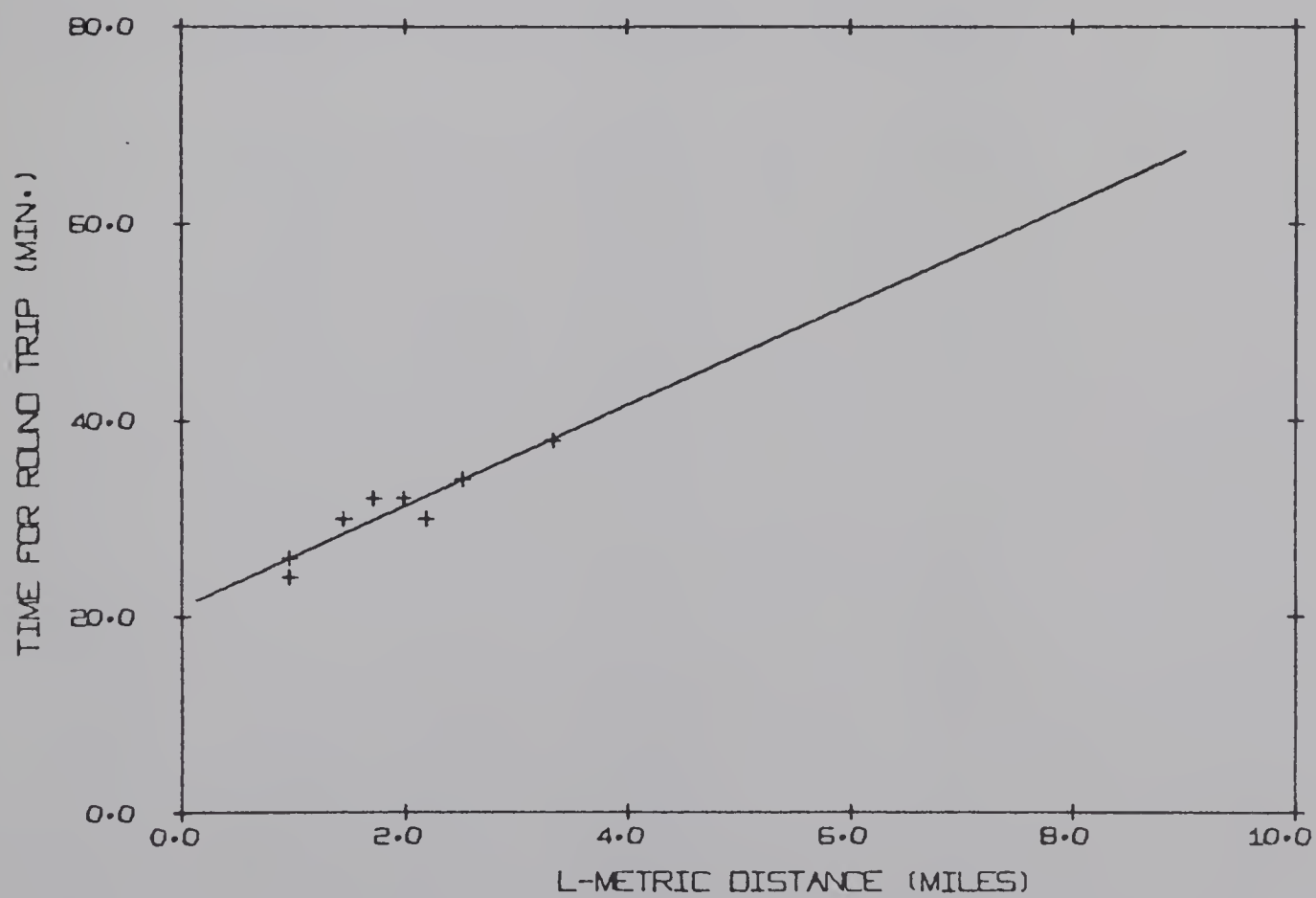


FIGURE C-12-2 TRAVEL TIME - NORTHSIDE TO TRANSFER STATION

APPENDIX D

DISTRIBUTION AND PARAMETERS OF THE ROUTES

The Tables D-1,3 give the environmental data input for the simulations of the years 1970, 1976 and 1981. This data gives the pertinent parameters of the routes that serve to calculate the quantity of refuse generated weekly in each sub-area, and the location of these sub-areas.

In the case of 1970 this is actual data as obtained from the City Sanitation Department. The data for 1976 and 1981 was calculated from projections of the population and population densities as obtained from the City Planning Department.

These projections included a slight increase in population density in most of the present established areas, with the main part of the population increase located in new developing areas. These new areas were introduced by adding new routes in the data.

TABLE D-1 CITY WIDE ROUTE PARAMETERS FOR 1970

ROUTE	LOCATION		NUMBER OF HOUSEHOLDS	PER CENT APARTMENT	COLLECTION TIME
	X	Y			
1	-3.46	-1.14	994	0.0	57.50
2	-3.84	-1.33	1054	0.0	56.70
3	-3.84	-0.35	1160	2.7	57.70
4	-3.84	1.09	1416	9.8	57.00
5	-3.24	0.62	1167	2.0	56.90
6	-2.50	0.84	1537	36.0	55.40
7	-3.00	1.41	1763	13.5	54.20
8	-3.08	2.12	1371	37.8	54.70
9	-3.84	3.08	1247	20.8	55.00
10	-2.78	3.05	1493	14.5	59.00
11	-2.37	2.23	1298	33.9	57.60
12	-1.80	1.60	1242	34.2	50.50
13	-0.81	2.23	1449	44.0	51.50
14	-2.86	4.33	1654	14.7	55.40
15	-2.61	3.73	1391	11.5	53.90
16	-1.36	4.33	1708	0.8	56.50
17	-1.36	3.73	1508	5.3	56.50
18	-0.10	4.00	1763	9.7	50.00
19	0.65	3.68	1934	20.4	54.00
20	1.20	2.97	1290	7.2	55.30
21	2.18	2.78	1544	8.4	53.80
22	1.74	2.15	1376	3.0	58.90
23	0.38	1.33	1439	27.0	55.80
24	0.19	3.10	1308	14.4	50.80
25	-0.81	0.00	1218	53.0	52.10
26	-0.87	0.60	1416	44.5	50.00
27	-0.27	0.73	1365	39.2	51.60
28	1.00	4.11	1834	10.9	54.80
29	2.31	3.54	1584	3.6	58.40
30	-1.52	0.32	1249	69.2	58.70
31	-1.30	1.11	1613	85.4	47.00
32	-0.27	1.28	1394	20.0	49.80
33	-0.27	2.15	1702	9.1	50.60
34	0.27	2.15	1640	8.0	51.50
35	0.00	2.70	1618	12.7	51.00
36	-1.93	-0.87	1383	7.6	57.50
37	-2.48	-1.90	1425	7.6	50.70
38	-1.60	-2.01	1595	10.3	51.40
39	-0.90	-2.91	1996	21.1	51.70
40	-0.98	-1.50	2126	23.8	52.20
41	-0.87	-0.84	2081	28.1	62.00
42	-0.24	-1.25	1830	24.9	57.40
43	0.00	-2.04	1643	17.9	55.90
44	1.09	-2.48	1735	6.1	53.80
45	0.92	-1.33	1572	13.3	56.50
46	0.60	-0.51	2107	23.4	50.40
47	1.28	-0.68	1841	15.3	52.20
48	1.28	0.73	1826	7.8	57.10
49	2.20	1.14	1547	4.7	59.00
50	2.78	1.03	1669	10.6	51.30

TABLE D-1 CONTINUED

ROUTE	LOCATION		NUMBER OF HOUSEHOLDS	PER CENT APARTMENT	COLLECTION TIME
	X	Y			
51	2.15	-0.19	1947	8.1	52.80
52	3.27	2.37	2606	2.5	53.00
53	-1.71	-3.10	1660	17.4	47.80
54	2.10	-1.11	2017	10.8	51.80
55	-1.36	-4.28	1179	0.0	47.00
56	-3.68	-3.81	1327	15.2	56.40
57	-2.34	-3.84	1494	14.8	50.40
58	2.04	7.14	1483	30.5	54.50
59	0.54	5.64	1375	3.0	61.50
71	-4.41	-0.81	1229	0.3	58.20
72	-4.39	-1.52	1170	12.3	55.10
73	-4.99	-1.20	287	0.0	58.00
74	-4.60	-0.76	1750	20.0	55.00
75	-5.40	-0.49	1750	20.0	55.00
76	-4.60	0.00	1750	20.0	55.00
77	-4.69	0.70	2000	10.0	55.00
78	-4.69	1.30	2000	10.0	55.00

ROUTES ACTUALLY SERVICED BY CITY SANITATION DEPARTMENT
IN 1970 WERE THESE WITH EXCEPTION OF NO.74 TO 78

TABLE D-2 CITY WIDE ROUTE PARAMETERS FOR 1976

ROUTE	LOCATION		NUMBER OF HOUSEHOLDS	PER CENT APARTMENT	COLLECTION TIME
	X	Y			
1	-3.46	-1.14	994	0.0	57.50
2	-3.84	-1.33	1054	0.0	56.70
3	-3.84	-0.35	1160	2.7	57.70
4	-3.84	1.09	1416	9.8	57.00
5	-3.24	0.62	1167	2.0	56.90
6	-2.50	0.84	1537	36.0	55.40
7	-3.00	1.41	1869	18.5	54.20
8	-3.08	2.12	1453	41.4	54.70
9	-3.84	3.08	1247	20.8	55.00
10	-2.78	3.05	1493	14.5	59.00
11	-2.37	2.23	1375	37.6	57.60
12	-1.80	1.60	1366	40.2	50.50
13	-0.81	2.23	1681	51.5	51.50
14	-2.86	4.33	1654	14.7	55.40
15	-2.61	3.73	1391	11.5	53.90
16	-1.36	4.33	1708	0.8	56.50
17	-1.36	3.73	1508	5.3	56.50
18	-0.10	4.00	1763	9.7	50.00
19	0.65	3.68	1934	20.4	54.00
20	1.20	2.97	1290	7.2	55.30
21	2.18	2.78	1729	18.2	53.80
22	1.74	2.15	1541	13.3	58.90
23	0.38	1.33	1439	27.0	55.80
24	0.19	3.10	1360	17.7	50.80
25	-0.81	0.00	1425	59.8	52.10
26	-0.87	0.60	1416	44.5	50.00
27	-0.27	0.73	1426	41.9	51.60
28	1.00	4.11	1834	10.9	54.80
29	2.31	3.54	1774	13.9	58.40
30	-1.52	0.32	1461	73.5	58.70
31	-1.30	1.11	1718	86.5	47.00
32	-0.27	1.28	1457	23.4	49.80
33	-0.27	2.15	1770	12.5	50.60
34	0.27	2.15	1705	11.5	51.50
35	0.00	2.70	1683	16.0	51.00
36	-1.93	-0.87	1383	7.6	57.50
37	-2.48	-1.90	1425	7.6	50.70
38	-1.60	-2.01	1738	17.7	51.40
39	-0.90	-2.91	2255	30.2	51.70
40	-0.98	-1.50	2317	30.2	52.20
41	-0.87	-0.84	2706	44.7	62.00
42	-0.24	-1.25	2379	42.0	57.40
43	0.00	-2.04	1643	17.9	55.90
44	1.09	-2.48	1735	6.1	53.80
45	0.92	-1.33	1572	13.3	56.50
46	0.60	-0.51	2107	23.4	50.40
47	1.28	-0.68	1841	15.3	52.20
48	1.28	0.73	1826	7.8	57.10
49	2.20	1.14	1547	4.7	59.00
50	2.78	1.03	1669	10.6	51.30

TABLE D-2 CONTINUED

ROUTE	LOCATION		NUMBER OF HOUSEHOLDS	PER CENT APARTMENT	COLLECTION TIME
	X	Y			
51	2.15	-0.19	1947	8.1	52.80
52	3.27	2.37	3467	15.0	53.00
53	-1.71	-3.10	1876	26.8	47.80
54	2.10	-1.11	2017	10.8	51.80
55	-1.36	-4.28	1862	10.0	47.00
56	-3.68	-3.81	2750	10.0	56.40
57	-2.34	-3.84	2360	20.0	50.40
58	1.74	4.80	1722	50.0	54.00
59	0.24	4.80	1592	50.0	54.00
60	0.24	5.31	1722	50.0	54.00
61	1.74	5.31	1592	50.0	54.00
71	-4.41	-0.81	1229	0.3	58.20
72	-4.39	-1.52	1170	12.3	55.10
73	-4.99	-1.20	850	0.0	58.00
74	-4.60	-0.76	1750	20.0	55.00
75	-5.40	-0.49	1750	20.0	55.00
76	-4.60	0.00	1750	20.0	55.00
77	-4.69	0.70	2000	10.0	55.00
78	-4.69	1.30	2000	10.0	55.00
80	-1.99	-5.26	1000	0.0	57.50
82	1.20	-4.25	1875	15.0	55.00
83	2.40	-4.25	1875	15.0	55.00
86	-2.10	5.04	1250	0.0	60.00
87	-1.58	6.10	1250	0.0	60.00
88	3.60	3.60	1500	0.0	60.00
90	-6.32	-0.76	1750	0.0	57.50

TABLE D-3 CITY WIDE ROUTE PARAMETERS FOR 1981

ROUTE	LOCATION		NUMBER OF HOUSEHOLDS	PER CENT APARTMENT	COLLECTION TIME
	X	Y			
1	-3.46	-1.14	994	0.0	57.50
2	-3.84	-1.33	1054	0.0	56.70
3	-3.84	-0.35	1160	2.7	57.70
4	-3.84	1.09	1416	9.8	57.00
5	-3.24	0.62	1167	2.0	56.90
6	-2.50	0.84	1537	36.0	55.40
7	-3.00	1.41	1869	18.5	54.20
8	-3.08	2.12	1453	41.4	54.70
9	-3.84	3.08	1247	20.8	55.00
10	-2.78	3.05	1493	14.5	59.00
11	-2.37	2.23	1375	37.6	57.60
12	-1.80	1.60	1366	40.2	50.50
13	-0.81	2.23	1681	51.5	51.50
14	-2.86	4.33	1654	14.7	55.40
15	-2.61	3.73	1391	11.5	53.90
16	-1.36	4.33	1708	0.8	56.50
17	-1.36	3.73	1508	5.3	56.50
18	-0.10	4.00	1763	9.7	50.00
19	0.65	3.68	1934	20.4	54.00
20	1.20	2.97	1290	7.2	55.30
21	2.18	2.78	1729	18.2	53.80
22	1.74	2.15	1541	13.3	58.90
23	0.38	1.33	1439	27.0	55.80
24	0.19	3.10	1360	17.7	50.80
25	-0.81	0.00	1425	59.8	52.10
26	-0.87	0.60	1416	44.5	50.00
27	-0.27	0.73	1426	41.9	51.60
28	1.00	4.11	1834	10.9	54.80
29	2.31	3.54	1774	13.9	58.40
30	-1.52	0.32	1461	73.5	58.70
31	-1.30	1.11	1718	86.5	47.00
32	-0.27	1.28	1457	23.4	49.80
33	-0.27	2.15	1770	12.5	50.60
34	0.27	2.15	1705	11.5	51.50
35	0.00	2.70	1683	16.0	51.00
36	-1.93	-0.87	1383	7.6	57.50
37	-2.48	-1.90	1425	7.6	50.70
38	-1.60	-2.01	1738	17.7	51.40
39	-0.90	-2.91	2255	30.2	51.70
40	-0.98	-1.50	2317	30.2	52.20
41	-0.87	-0.84	2706	44.7	62.00
42	-0.24	-1.25	2379	42.0	57.40
43	0.00	-2.04	1643	17.9	55.90
44	1.09	-2.48	1735	6.1	53.80
45	0.92	-1.33	1572	13.3	56.50
46	0.60	-0.51	2107	23.4	50.40
47	1.28	-0.68	1841	15.3	52.20
48	1.28	0.73	1826	7.8	57.10
49	2.20	1.14	1547	4.7	59.00
50	2.78	1.03	1669	10.6	51.30

TABLE D-3 CONTINUED

ROUTE	LOCATION		NUMBER OF HOUSEHOLDS	PER CENT APARTMENT	COLLECTION TIME
	X	Y			
51	2.15	-0.19	1947	8.1	52.80
52	3.27	2.37	3467	15.0	53.00
53	-1.71	-3.10	1876	26.8	47.80
54	2.10	-1.11	2017	10.8	51.80
55	-1.36	-4.28	1862	10.0	47.00
56	-4.00	-2.89	2375	10.0	57.50
57	-2.34	-3.84	2360	20.0	50.40
58	1.74	4.80	2500	50.0	54.00
59	0.24	4.80	2500	50.0	54.00
60	0.24	5.31	2500	50.0	54.00
61	1.74	5.31	2500	50.0	54.00
71	-4.41	-0.81	1229	0.3	58.20
72	-4.39	-1.52	1170	12.3	55.10
73	-4.99	-1.20	850	0.0	58.00
74	-4.60	-0.76	1750	20.0	55.00
75	-5.40	-0.49	1750	20.0	55.00
76	-4.60	0.00	1750	20.0	55.00
77	-4.69	0.70	2000	10.0	55.00
78	-4.69	1.30	2000	10.0	55.00
79	-4.00	-4.25	2375	10.0	57.50
80	-1.99	-5.26	1700	10.0	57.50
81	-1.20	-5.26	1700	10.0	57.50
82	1.20	-4.25	2462	15.0	55.00
83	2.40	-4.25	2462	15.0	55.00
84	1.20	-5.26	2462	15.0	55.00
85	2.40	-5.26	2462	15.0	55.00
86	-2.10	5.04	2888	10.0	60.00
87	-1.58	6.10	2888	10.0	60.00
88	3.60	3.60	2888	10.0	60.00
89	3.24	4.25	2888	10.0	60.00
90	-6.32	-0.76	2212	10.0	57.50
91	-6.32	-2.10	2212	10.0	57.50

A P P E N D I X E

PROGRAM LISTING AND SAMPLE OUTPUT

This appendix gives the model computer program written in Fortran IV for use on an IBM 360 system. The program is broken up into sub-routines corresponding to the quantity and cost generators, and the optimizer as described previously.

A sample output is also given. This run is a validation run that was carried out to compare the simulated system to the actual 1970 system behavior.


```

C*****SOLID000
C      SOLID001
C***** PROGRAM SOLID *****      SOLID002
C      SOLID003
C      PROGRAM WHOSE PURPOSE IS TO SIMULATE THE CITY OF EDMONTON      SOLID004
C      SOLID WASTES COLLECTION SYSTEM OVER A ONE YEAR PERIOD.      SOLID005
C      GIVEN A NUMBER OF DIFFERENT COLLECTION POLICY ALTERNATIVES      SOLID006
C      THE SYSTEM IS SIMULATED UNDER THE COST CONDITIONS OF EACH      SOLID007
C      AND A CHOICE IS MADE OF THE BEST POLICY TO PERSUE.      SOLID008
C      SOLID009
C      *** VARIABLES ARE,      SOLID010
C      1. INITIAL      SOLID011
C      NORUN=THE TRIAL NUMBER      SOLID012
C      NYEAR=YEAR OF SIMULATION      SOLID013
C      IWEK=WEEK IN YEAR, FIRST WEEK IN JAN. BEING WEEK 1      SOLID014
C      I=INDEX DENOTING CITY ROUTE      SOLID015
C      J=INDEX DENOTING THE ALTERNATIVE      SOLID016
C      N=NUMBER OF ROUTES      SOLID017
C      M=NUMBER OF COLLECTION ALTERNATIVES      SOLID018
C      2. THE ROUTE PARAMETERS      SOLID019
C      NOROU=THE I.D. NUMBER OF THE ROUTE      SOLID020
C      NOHOU=THE NUMBER OF HOUSEHOLDS IN THE ROUTE      SOLID021
C      XROUT=THE X COORDINATE OF THE ROUTE IN MILES      SOLID022
C      YROUT=THE Y COORDINATE OF THE ROUTE IN MILES      SOLID023
C      PCAPT=PER CENT APARTMENT AND TRADE HOUSEHOLD EQUIVALENT      SOLID024
C      CTIME=TIME REQUIRED IN MINUTES TO COLLECT ONE STANDARD      SOLID025
C      LOAD IN THE ROUTE      SOLID026
C      A=TOTAL NUMBER OF LOADS IN WEEK FOR ROUTE I      SOLID027
C      WT=WEIGHT OF REFUSE FOR WEEK FROM ROUTE I      SOLID028
C      DENS=DENSITY OF REFUSE FROM ROUTE I FOR WEEK      SOLID029
C      3. THE ALTERNATIVE PARAMETERS      SOLID030
C      ITITL=THE NAME OF THE ALTERNATIVE      SOLID031
C      XSITE=THE X COORDINATE OF THE ALTERNATIVE'S DUMPING SITE      SOLID032
C      YSITE=THE Y COORDINATE OF THE ALTERNATIVE'S DUMPING SITE      SOLID033
C      BCAPY=CAPACITY IN POUNDS PER WEEK OF THE DUMPING SITE      SOLID034
C      C=THE UNIT COST PER LOAD OF COLLECTING A STANDARD LOAD      SOLID035
C      FROM ROUTE I ACCORDING TO ALTERNATIVE J      SOLID036
C      FCTIM=RATIO OF THE TIME REQUIRED TO COLLECT A LOAD UNDER      SOLID037
C      ALTERNATIVE J TO THE TIME REQUIRED FOR A STANDARD LOAD      SOLID038
C      FLOAD=RATIO OF THE WEIGHT OF A LOAD UNDER ALTERNATIVE J      SOLID039
C      TO THE WEIGHT OF A STANDARD LOAD      SOLID040
C      RCOST=COST PER MINUTE OF CREW AND VEHICLE OF ALTERNATIVE J      SOLID041
C      TCOST=COST PER 1.5 TON OF PROCESSING REFUSE AT DUMPING      SOLID042
C      SITE OF ALTERNATIVE J      SOLID043
C      TRACN=COST OF TRANSPORTATION OF 1.5 TON FROM DUMPING      SOLID044
C      SITE OF ALTERNATIVE J TO THE ULTIMATE DISPOSAL SITE      SOLID045
C      4. THE OUTPUT VARIABLES      SOLID046
C      AWEK=WEEKLY TOTAL WEIGHT OF REFUSE COLLECTED      SOLID047
C      AWEK=WEKLY TOTAL LOADS OF REFUSE COLLECTED      SOLID048
C      TOTCN=WEEKLY COST OF COLLECTION      SOLID049
C      WYFAR=YEARLY TOTAL WEIGHT OF REFUSE COLLECTED      SOLID050
C      AYEAR=YEARLY TOTAL LOADS OF REFUSE COLLECTED      SOLID051
C      YTCOS=YEARLY TOTAL COST      SOLID052
C      BYTOT=YEARLY TOTAL WEIGHT DISPOSED OF ACCORDING TO      SOLID053
C      ALTERNATIVE J      SOLID054
C      AROUY=TOTAL NUMBER OF LOADS COLLECTED IN YEAR FOR ROUTE I      SOLID055
C      AKROU=TOTAL NUMBER OF LOADS COLLECTED IN YEAR FROM      SOLID056
C      ROUTE I ACCORDING TO ALTERNATIVE J      SOLID057
C      SOLID058
C*****SOLID059

```


	COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),	SOLID060
	1 TCost(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)	SOLID061
	2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),	SOLID062
	3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9),	SOLID063
	4 AROUY(99),ITITL(30,9),TRACO(9)	SOLID064
	IX=256199351	SOLID065
	YTCOS=0.0	SOLID066
	IWEEK=1	SOLID067
	CALL PUTIN(NORUN,NYEAR,N,M,NAND1,AYEAR,WYEAR)	SOLID068
	CALL COSTS(N,M,NAND1)	SOLID069
2	CONTINUE	SOLID070
	CALL QUANT(N,NYEAR,IWEEK,AYEAR,WYEAR,IX,AWEEK,WEEK,DWEEK)	SOLID071
	CALL SETUP(NAND1,M,AWEEK,DWEEK)	SOLID072
	CALL TRANS(NAND1,M,NOTAB,IZERO,TOTCO)	SOLID073
	CALL OUTPU(IWEEK,M,N,NAND1,WEEK,AWEEK,TOTCO,YTCOS)	SOLID074
	IWEEK=IWEEK+1	SOLID075
	IF(IWEEK-53)2,3,3	SOLID076
3	CONTINUE	SOLID077
	CALL FINAL(N,M,NORUN,AYEAR,WYEAR,YTCOS,NYEAR)	SOLID078
	STOP	SOLID079
	END	SOLID080
		SOLID081


```

SUBROUTINE PUTIN(NORUN,NYEAR,N,M,NAND1,AYEAR,WYEAR)
C *****
C
C   ** PUTIN **
C   A SUBROUTINE TO READ THE INPUT DATA
C
C *****
C
COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),
1 Tcost(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)
2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),
3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9),
4 AROUY(99),ITITL(30,9),TRACO(9)
READ(5,900)NORUN,NYEAR,N,M
900 FORMAT(4I4)
NAND1=N+1
C***** READ THE ROUTE DATA
DO 901 I=1,N
READ(5,902)NOROU(I),PCAPT(I),NOHOU(I),XROUT(I),YROUT(I),CTIME(I)
902 FORMAT(I5,5X,F10.1,I4,6X,3F10.1)
901 CONTINUE
C***** READ THE DISPOSAL ALTERNATIVES DATA
DO 903 J=1,M
READ(5,904)XSITE(J),YSITE(J),BCAPY(J),WTIME(J),FLOAD(J),FCTIM(J),
1 RCOST(J),TCOST(J),TRACO(J)
904 FORMAT(F5.1,F5.1,F10.0,6F10.4)
903 CONTINUE
C***** INITIALIZE THE STARTING VALUES
DO 905 I=1,N
905 AROUY(I)=0.0
DO 910 J=1,M
910 BYTOT(J)=0.0
DO 911 J=1,M
DO 911 I=1,N
911 AKROU(I,J)=0.0
AYEAR=0.0
WYEAR=0.0
DO 907 J=1,M
READ(5,908)(ITITL(I,J),I=1,30)
908 FORMAT(30A2)
907 CONTINUE
WRITE(6,999)NORUN
999 FORMAT('1','***** RUN NO.',I3,' *****')
WRITE(6,980)(J,J=1,M)
980 FORMAT('0','WEEK COST/WK LB/WK LOADS LB/LD TO ',
1 7('NO.',I1,6X))
RETURN
END

```

PUTIN000
 PUTIN001
 PUTIN002
 PUTIN003
 PUTIN004
 PUTIN005
 PUTIN006
 PUTIN007
 PUTIN008
 PUTIN009
 PUTIN010
 PUTIN011
 PUTIN012
 PUTIN013
 PUTIN014
 PUTIN015
 PUTIN016
 PUTIN017
 PUTIN018
 PUTIN019
 PUTIN020
 PUTIN021
 PUTIN022
 PUTIN023
 PUTIN024
 PUTIN025
 PUTIN026
 PUTIN027
 PUTIN028
 PUTIN029
 PUTIN030
 PUTIN031
 PUTIN032
 PUTIN033
 PUTIN034
 PUTIN035
 PUTIN036
 PUTIN037
 PUTIN038
 PUTIN039
 PUTIN040
 PUTIN041
 PUTIN042
 PUTIN043
 PUTIN044
 PUTIN045
 PUTIN046
 PUTIN047


```

SUBROUTINE QUANT(N,NYEAR,IWEEK,AYEAR,WYEAR,IX,AWEEK,WWEEK,DWEEK)  QUANT000
C*****QUANT001
C  QUANT002
C  ** QUANT **  QUANT003
C  A SUBROUTINE TO CALCULATE THE QUANTITY OF REFUSE GENERATED  QUANT004
C  IN EACH ROUTE AT A GIVEN TIME (NYEAR & IWEEK)  QUANT005
C*****QUANT006
C  QUANT007
C  COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),  QUANT008
1  TCOST(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)  QUANT009
2  ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),  QUANT010
3  INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9),  QUANT011
4  AROUY(99),ITITL(30,9),TRACO(9)  QUANT012
YIN=0.4656613E-9  QUANT013
AVLBH=45.06 + 0.051*((NYEAR-1966)*52+IWEEK)  QUANT014
F=0.0  QUANT015
DO 209 J=1,12  QUANT016
IY=IX*65539  QUANT017
IF(IY)207,208,208  QUANT018
207 IY=IY+2147483647+1  QUANT019
208 YFL=IY  QUANT020
YFL=YFL*YIN  QUANT021
IX=IY  QUANT022
209 F=F+YFL  QUANT023
FRAND=(F-6.0)*0.08 +1.0  QUANT024
DO 210 I=1,N  QUANT025
F1=28.85 - 0.2710*PCAPT(I)  QUANT026
F2= 9.23 - 0.0669*PCAPT(I)  QUANT027
F3=11.04 - 0.0801*PCAPT(I)  QUANT028
F5= 3.84 - 0.0244*PCAPT(I)  QUANT029
F1CO=0.1208304*IWEEK-3.522  QUANT030
F2CO=0.2416608*IWEEK-4.410  QUANT031
F3CO=0.3624912*IWEEK-1.072  QUANT032
F5CO=0.6041520*IWEEK-0.445  QUANT033
TRLBH=100.+F1*COS(F1CO)+F2*COS(F2CO)+F3*COS(F3CO)+F5*COS(F5CO)  QUANT034
210 WT(I)=FRAND*TRLBH*AVLBH/100.0  QUANT035
DO 220 I=1,N  QUANT036
DENS(I)=1.41+0.0257*WT(I)  QUANT037
F=0.0  QUANT038
DO 211 J=1,12  QUANT039
IY=IX*65539  QUANT040
IF(IY)212,213,213  QUANT041
212 IY=IY+2147483647+1  QUANT042
213 YFL=IY  QUANT043
YFL=YFL*YIN  QUANT044
IX=IY  QUANT045
211 F=F+YFL  QUANT046
FRAND=(F-6.0)*0.0985+1.0  QUANT047
220 DENS(I)=FRAND*DENS(I)  QUANT048
DO 230 I=1,N  QUANT049
WT(I)=NOHOU(I)*WT(I)  QUANT050
A(I)=WT(I)/((DENS(I)*1000.0)+0.50  QUANT051
IA=A(I)  QUANT052
230 A(I)=IA  QUANT053
AWEEK=0.0  QUANT054
WWEEK=0.0  QUANT055
DO 235 I=1,N  QUANT056
AROUY(I)=AROUY(I) + A(I)  QUANT057
AWEEK=AWEEK + A(I)  QUANT058
235 WWEEK=WWEEK + WT(I)  QUANT059
DWEEK=WWEEK/AWEEK  QUANT060
AYEAR=AYEAR + AWEEK  QUANT061
WYEAR=WYEAR + WWEEK  QUANT062
RETURN  QUANT063
END  QUANT064

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SUBROUTINE COSTS(N,M,NAND1)
C ***** COSTS000
C ***** COSTS001
C COSTS002
C ** COSTS ** COSTS003
C A SUBROUTINE TO CALCULATE THE COST PER UNIT STANDARD LOAD COSTS004
C UNDER EACH ALTERNATIVE FOR EACH ROUTE. COSTS005
C COSTS006
C ***** COSTS007
C COSTS008
COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9), COSTS009
1 TCost(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9) COSTS010
2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60), COSTS011
3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9), COSTS012
4 AROUY(99),ITITL(30,9),TRACO(9) COSTS013
DO 400 J=1,M COSTS014
DO 400 I=1,N COSTS015
DIST=ABS(XROUT(I)-XSITE(J)) + ABS(YROUT(I)-YSITE(J)) COSTS016
TTIME=WTIME(J) + 4.947*DIST COSTS017
400 C(I,J)=RCOST(J)*(CTIME(I)*FCTIM(J)+TTIME)/FLOAD(J) COSTS018
1 +TCOST(J)+TRACO(J) COSTS019
DO 401 J=1,M COSTS020
401 C(NAND1,J)=0.0 COSTS021
NOROU(NAND1)=100 COSTS022
RETURN COSTS023
END COSTS024

```



```

SUBROUTINE SETUP(N,M,AWEEK,DWEEK)
C *****
C
C   ** SETUP **
C   A SUBROUTINE TO PRODUCE AN INITIAL STARTING SOLUTION FOR
C   THE LINEAR PROGRAMING ALGORITHM OF THE SUBROUTINE TRANS.
C *****
C
COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),
1 TCost(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)
2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),
3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9),
4 AROUY(99),ITITL(30,9),TRACO(9)
BTOT=0.0
DO 300 J=1,M
IF(BCAPY(J))305,302,302
305 B(J)=AWEEK
GO TO 300
302 B(J)=BCAPY(J)/DWEEK +0.5
IB=B(J)
B(J)=IB
300 BTOT=BTOT + B(J)
A(N)=BTOT - AWEEK
DO 100 I=1,N
DO 100 J=1,M
100 X(I,J)=0.0
C *****SETTING UP INITIAL TABLEU*****
J=1
RESTB=B(J)
DO 101 I=1,N
DUMC=C(I,J)
DO 102 II=I,N
IF(C(II,J)-DUMC)103,103,102
103 III=II
DUMC=C(II,J)
102 CONTINUE
DO 104 JJ=1,M
DUMC=C(I,JJ)
C(I,JJ)=C(III,JJ)
104 C(III,JJ)=DUMC
DUMC=A(I)
A(I)=A(III)
A(III)=DUMC
DUMC=NOROU(I)
NOROU(I)=NOROU(III)
NOROU(III)=DUMC
RESTB=RESTB-A(I)
IF(RESTB)105,106,107
107 X(I,J)=A(I)
GO TO 101
106 IF(J-M)117,107,117
117 A(I)=A(I)+1.0
B(M)=B(M)+1
RESTB=-1.0
105 X(I,J)=RESTB+A(I)
J=J+1
X(I,J)=-RESTB
RESTB=B(J)-X(I,J)
172 IF(RESTB)170,168,101

```

SETUP000
 SETUP001
 SETUP002
 SETUP003
 SETUP004
 SETUP005
 SETUP006
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 SETUP052
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 SETUP056
 SETUP057
 SETUP058
 SETUP059

168	J=J+1	SETUP060
	IF(J-M)173,173,101	SETUP061
173	X(I,J)=1.0	SETUP062
	RESTB=B(J)-1.0	SETUP063
	A(I)=A(I)+1.0	SETUP064
	B(M)=B(M)+1.0	SETUP065
	GO TO 101	SETUP066
170	X(I,J)=B(J)	SETUP067
	J=J+1	SETUP068
	RESTB=0.0	SETUP069
	DO 171 JJ=1,M	SETUP070
171	RESTB=RESTB+X(I,JJ)	SETUP071
	X(I,J)=A(I)-RESTB	SETUP072
	RESTB=B(J)-X(I,J)	SETUP073
	GO TO 172	SETUP074
101	CONTINUE	SETUP075
	RETURN	SETUP076
	END	SETUP077

SUBROUTINE TRANS(N,M,NOTAB,IZERO,TOTCO)	TRANS000
*****	TRANS001
	TRANS002
SUBROUTINE TRANS *** A SUBROUTINE TO SOLVE THE PROBLEM OF TRANS-	TRANS003
PORTATION ROUTE ASSIGNMENT BY THE LINEAR PROGRAMMING	TRANS004
TRANSPORTATION METHOD.	TRANS005
REFERENCE -- LINEAR PROGRAMMING - SAUL I. GASS - MCGRAW-HILL, 1964	TRANS006
	TRANS007
DIMENSION C(N,M),X(N,M),A(N),B(M),U(N),V(M),NOROU(N),	TRANS008
1 INII(3*M),INJJ(3*M),INI(3*M),INJ(3*M)	TRANS009
	TRANS010
TCOST=MINIMUM TOTAL COST	TRANS011
N=NUMBER OF ROWS	TRANS012
M=NUMBER OF COLUMNS	TRANS013
NOTAB=NUMBER OF ITERATIONS	TRANS014
IZERO=NUMBER OF DEGENERATE SOLUTIONS	TRANS015
C(N,M)=COST MATRIX	TRANS016
X(N,M)=SOLUTION MATRIX OF ASSIGNMENTS	TRANS017
A(N)=QUANTITIES ALLOCATED TO EACH ROW	TRANS018
B(M)=QUANTITIES ALLOCATED TO EACH COLUMN	TRANS019
U(N)=INDIRECT COSTS FOR ROWS	TRANS020
V(M)=INDIRECT COSTS FOR COLUMNS	TRANS021
NOROU(N)=ROW IDENTIFICATION NUMBER	TRANS022
INII,INJJ,INI,INJ, ARE THE INDICES OF THE NODAL AND PATH ELEMENTS	TRANS023
	TRANS024
*****	TRANS025
	TRANS026
COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),	TRANS027
1 TCOST(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)	TRANS028
2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),	TRANS029
3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NPHNU(99),AKRNU(99,9),	TRANS030
4 AROUY(99),ITITL(30,9),TRACO(9)	TRANS031
NOTAB=0	TRANS032
*****FINDING THE INDIRECT COSTS*****	TRANS033
198 DO 108 I=1,N	TRANS034
108 U(I)=101101.0	TRANS035
DO 109 J=1,M	TRANS036
109 V(J)=101101.0	TRANS037
II1=1	TRANS038
NOTAB=NOTAB+1	TRANS039
112 IF(X(II1,1))110,110,111	TRANS040
110 II1=II1+1	TRANS041
GO TO 112	TRANS042
111 U(II1)=C(II1,1)	TRANS043
V(1)=0.0	TRANS044
127 J=1	TRANS045
116 DO 113 I=1,N	TRANS046
IF(X(I,J))113,113,114	TRANS047
114 IF(U(I)-101101.0)113,129,113	TRANS048
129 IF(V(J)-101101.0)115,113,115	TRANS049
115 U(I)=C(I,J)-V(J)	TRANS050
113 CONTINUE	TRANS051
IF(J-M)130,124,124	TRANS052
130 J=J+1	TRANS053
DO 118 I=1,N	TRANS054
IF(X(I,J))118,118,120	TRANS055
120 IF(U(I)-101101.0)121,118,121	TRANS056
121 IF(V(J)-101101.0)118,122,118	TRANS057
122 V(J)=C(I,J)-U(I)	TRANS058
GO TO 116	TRANS059


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118  CONTINUE                                TRANS060
      IF(J-M)116,124,124                    TRANS061
124  DO 125 I=1,N                            TRANS062
      IF(U(I)-101101.0)125,127,125          TRANS063
125  CONTINUE                                TRANS064
      DO 128 JJ=1,M                          TRANS065
      IF(V(JJ)-101101.0)128,127,128          TRANS066
128  CONTINUE                                TRANS067
C*****FINDING THE PIVOT ELEMENTS,INII(1),INJJ(1)***** TRANS068
      IZERO=0                                TRANS069
      BIGES=0.0                              TRANS070
      DO 140 I=1,N                            TRANS071
      DO 140 J=1,M                            TRANS072
      DUMC=U(I)+V(J)-C(I,J)                  TRANS073
      IF(DUMC)140,141,142                    TRANS074
141  IF(X(I,J))143,143,140                   TRANS075
143  IZERO=IZERO+1                           TRANS076
      GO TO 140                               TRANS077
142  IF(DUMC-BIGES)140,140,144               TRANS078
144  INII(1)=I                               TRANS079
      INJJ(1)=J                               TRANS080
      BIGES=DUMC                              TRANS081
140  CONTINUE                                TRANS082
      IF(BIGES-0.0)199,199,145               TRANS083
C*****FINDING THE NODAL ELEMENTS,INII(K),INJJ(K)***** TRANS084
145  SMAL=1000000.0                          TRANS085
      K=0                                    TRANS086
      DO 166 J=1,M                            TRANS087
      I=INII(1)                              TRANS088
      IF(X(I,J))166,166,167                  TRANS089
167  K=K+1                                    TRANS090
      INI(K)=INII(1)                         TRANS091
      INJ(K)=J                               TRANS092
166  CONTINUE                                TRANS093
      DO 146 J=1,M                            TRANS094
      DO 146 I=1,N                            TRANS095
      NDUM=0                                  TRANS096
      IF(X(I,J))146,146,147                  TRANS097
147  DO 146 JJ=1,M                           TRANS098
      IF(J-JJ)148,146,146                    TRANS099
148  IF(X(I,JJ))146,146,151                  TRANS100
151  IF(J-1)149,149,152                     TRANS101
152  DO 153 II=1,K                           TRANS102
      IF(I-INI(II))153,146,153               TRANS103
153  CONTINUE                                TRANS104
149  K=K+1                                    TRANS105
      INI(K)=I                               TRANS106
      INJ(K)=JJ                              TRANS107
      IF(NDUM)146,150,146                    TRANS108
150  K=K+1                                    TRANS109
      INI(K)=I                               TRANS110
      INJ(K)=J                               TRANS111
      NDUM=1                                  TRANS112
146  CONTINUE                                TRANS113
      DO 131 I=1,K                            TRANS114
      DO 131 II=1,K                           TRANS115
      IF(I-II)132,131,132                    TRANS116
132  IF(INI(I)-INI(II))131,133,131          TRANS117
133  IF(INJ(I)-INJ(II))131,134,131          TRANS118

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134  INI(II)=0                                TRANS119
      INJ(II)=0                                TRANS120
131  CONTINUE                                  TRANS121
C*****FINDING THE CLOSED PATH AMONG THE NODAL ELEMENTS*****TRANS122
158  DO 139 I=1,K                              TRANS123
      INII(I+1)=0.0                            TRANS124
139  INJJ(I+1)=0.0                            TRANS125
      DO 154 II=1,K                            TRANS126
        IF(II-2*(II/2))165,154,165            TRANS127
165  DO 154 I=1,K                              TRANS128
        IF(INI(I)-INII(II))154,169,154        TRANS129
169  IF(INJ(I)-INJJ(II))155,154,155          TRANS130
155  IF(INJ(I)-INJJ(1))159,160,159           TRANS131
159  DO 154 J=1,K                              TRANS132
        IF(J-I)156,154,156                    TRANS133
156  IF(INJ(I)-INJ(J))154,157,154           TRANS134
157  INII(II+1)=INI(I)                        TRANS135
      INJJ(II+1)=INJ(I)                      TRANS136
      INII(II+2)=INI(J)                      TRANS137
      INJJ(II+2)=INJ(J)                      TRANS138
154  CONTINUE                                  TRANS139
      DO 135 I=1,II                            TRANS140
        IF(INII(I))136,136,135                TRANS141
136  DO 135 J=1,K                              TRANS142
        IF(INI(J)-INII(I-1))135,137,135      TRANS143
137  IF(INJ(J)-INJJ(I-1))135,138,135        TRANS144
138  INI(J)=0                                  TRANS145
      INJ(J)=0                                  TRANS146
      GO TO 158                                TRANS147
135  CONTINUE                                  TRANS148
160  INII(II+1)=INI(I)                        TRANS149
      INJJ(II+1)=INJ(I)                      TRANS150
      K=II                                      TRANS151
C*****BRINGING THE PIVOT ELEMENT INTO THE SOLUTION MATRIX*****TRANS152
      DO 161 I=1,K,2                            TRANS153
        JJ=INJJ(I+1)                          TRANS154
        II=INII(I)                            TRANS155
        IF(X(II,JJ)-SMAL)162,164,161          TRANS156
162  SMAL=X(II,JJ)                            TRANS157
      GO TO 161                                TRANS158
164  X(II,JJ)=X(II,JJ) +1                     TRANS159
      A(II)=A(II)+1                            TRANS160
      B(JJ)=B(JJ) +1                          TRANS161
161  CONTINUE                                  TRANS162
      DO 163 I=1,K,2                            TRANS163
        JJ=INJJ(I)                            TRANS164
        JJ1=INJJ(I+1)                        TRANS165
        II=INII(I)                            TRANS166
        X(II,JJ)=X(II,JJ)+SMAL                TRANS167
163  X(II,JJ1)=X(II,JJ1)-SMAL                TRANS168
C*****CALCULATING THE TOTAL COST*****TRANS169
      TOTCO=0.0                                TRANS170
      DO 180 I=1,N                              TRANS171
        DO 180 J=1,M                            TRANS172
          IF(X(I,J))181,180,182                TRANS173
182  TOTCO=TOTCO + X(I,J)*C(I,J)             TRANS174
180  CONTINUE                                  TRANS175
      GO TO 198                                TRANS176
181  WRITE(6,183)I..J                        TRANS177
183  FORMAT('1','NEGATIVE VALUE FOR X(',2I3,').....') TRANS178
199  RETURN                                    TRANS179
      END                                        TRANS180

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SUBROUTINE OUTPU(IWEEK,M,N,NAND1,WEEK,AWEEK,TOTCO,YTCOS)
C *****
C
C      ** OUTPU **
C      A SUBROUTINE TO PRINT THE WEEKLY STATUS OF THE SYSTEM.
C *****
C
      COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),
1 TCOST(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)
2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),
3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9),
4 AROUY(99),ITITL(30,9),TRACO(9)
      TOTCO=0.0
      DWEEK=WEEK/AWEEK
      DO 500 J=1,M
      DO 500 I=1,NAND1
500  TOTCO=TOTCO + X(I,J)*C(I,J)
      DO 501 I=1,NAND1
      DO 501 II=I,NAND1
      IF(NOROU(I)-NOROU(II)) 501,501,502
502  DUMC=NOROU(I)
      NOROU(I)=NOROU(II)
      NOROU(II)=DUMC
      DO 503 J=1,M
      DUMC=X(I,J)
      X(I,J)=X(II,J)
      X(II,J)=DUMC
      DUMC=C(I,J)
      C(I,J)=C(II,J)
503  C(II,J)=DUMC
501  CONTINUE
      DO 504 J=1,M
      B(J)=0.0
      DO 505 I=1,N
505  B(J)=B(J) + X(I,J)
      B(J)=B(J)*DWEEK
504  BYTOT(J)=BYTOT(J)+B(J)
      DO 507 J=1,M
      DO 507 I=1,N
507  AKROU(I,J)=AKROU(I,J)+X(I,J)
      WRITE(6,599)IWEEK,TOTCO,WEEK,AWEEK,DWEEK,(B(J),J=1,M)
599  FORMAT(' ',I4,F10.1,F12.0,F8.0,F8.0,7F10.0)
      YTCOS=YTCOS+TOTCO
      RETURN
      END

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SUBROUTINE FINAL(N,M,NORUN,AYEAR,WYEAR,YTCOS,NYEAR)
C *****
C
C   ** FINAL **
C   A SUBROUTINE TO PRINT THE FINAL RESULT - THE SUMMARY
C   OF THE YEAR BEING SIMULATED.
C *****
C
COMMON C(99,9),XSITE(9),YSITE(9),FCTIM(9),FLOAD(9),RCOST(9),
1 TCOST(9),CTIME(99),WTIME(9),BYTOT(9),XROUT(99),YROUT(99),BCAPY(9)
2 ,B(9),A(99),NOROU(99),X(99,9),U(99),V(9),INII(60),INJJ(60),
3 INI(60),INJ(60),DENS(99),PCAPT(99),WT(99),NOHOU(99),AKROU(99,9),
4 AROUY(99),ITITL(30,9),TRACO(9)
WRITE(6,698)NORUN
698 FORMAT('1','***** RUN NO.'I3,' *****',/)
DYEAR=WYEAR/AYEAR
WRITE(6,998)NYEAR,N,M
998 FORMAT('0','YEAR ='I5,/, ' NUMBER OF ROUTES ='I3,/, ' NUMBER OF AL
TERNATIVES ='I2,/)
DO 906 J=1,M
WRITE(6,997)J,(ITITL(I,J),I=1,30)
997 FORMAT(' ','ALTERNATIVE NO.'I2,' -- ',30A2)
906 CONTINUE
WRITE(6,996)(J,J=1,M)
996 FORMAT('0','ALTERNATIVE NO.      ',7I10)
WRITE(6,995)(BCAPY(J),J=1,M)
WRITE(6,994)(RCOST(J),J=1,M)
WRITE(6,993)(TCOST(J),J=1,M)
WRITE(6,992)(TRACO(J),J=1,M)
WRITE(6,991)(WTIME(J),J=1,M)
WRITE(6,990)(FLOAD(J),J=1,M)
WRITE(6,989)(FCTIM(J),J=1,M)
995 FORMAT(' ','CAPACITY OF SITE (LB/WK)',7F10.1)
994 FORMAT(' ','COST PER MIN. COLLECTION',7F10.4)
993 FORMAT(' ','TREATMENT COST PER LOAD ',7F10.2)
992 FORMAT(' ','BULK TRANSPORT COST/LOAD',7F10.4)
991 FORMAT(' ','WAITING TIME (MIN/LD) ',7F10.2)
990 FORMAT(' ','LOAD CAPY COMPARED TO STD',7F9.2)
989 FORMAT(' ','COLL.TIME/LD COMP.TO STD',7F10.2)
WRITE(6,695)YTCOS,WYEAR,AYEAR,DYEAR
WRITE(6,694)(J,BYTOT(J),J=1,M)
694 FORMAT('0','TOTAL WEIGHT TO ALTERNATIVE ',
1 7('NO.'I1,' ='F12.1,/,29X))
695 FORMAT('0','TOTAL FOR YEAR IS -',/,3X,'TOTAL COST ='F12.1,/,3X,
1 'TOTAL WEIGHT='F12.1,/,3X,'TOTAL LOADS ='F12.1,/,3X,'AVERAGE DE
2 NSITY ='F9.1)
696 FORMAT(' ',I3,F8.1,12X,5F8.1)
WRITE(6,988)
988 FORMAT('0',/,1X,'** COMMENTS **',/,2X,'1 - IF CAPACITY OF SITE =-1
1 ,SITE CAPACITY IS UNLIMITED.',/,2X,'2 - TOTAL COST IS GIVEN IN TO
2 TAL CREW AND VEHICLE MINUTES.',/,2X,'3 - WEIGHT IS GIVEN IN POUNDS
3 ,DENSITY IN LB/LD.')
WRITE(6,698)NORUN
WRITE(6,697)(J,J=1,M)
697 FORMAT(' ','ROUTE LD/YR TO SITE NO.'I4,6I8)
DO 606 I=1,N
WRITE(6,696)NOROU(I),AROUY(I),(AKROU(I,J),J=1,M)
606 CONTINUE
RETURN

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***** FUN NO. 4 *****

WEEK	COST/WK	LB/WK	LOADS	LB/LD	TC NO.1	NO.2	NO.3
1	160749.9	4346908.	1696.	2563.	2842405.	620254.	381684.
2	165962.5	4680647.	1751.	2673.	3039346.	625512.	1013115.
3	154470.9	4070397.	1626.	2503.	2663558.	525697.	858638.
4	138601.6	3548946.	1461.	2429.	2361105.	485824.	699587.
5	151433.9	3812834.	1600.	2383.	2533151.	495668.	781631.
6	133358.6	3184891.	1405.	2267.	2121749.	426163.	634711.
7	150998.7	3997973.	1596.	2505.	2605195.	553604.	836662.
8	152239.5	3931821.	1606.	2448.	2599996.	555743.	773633.
9	142984.0	3489890.	1509.	2313.	2268775.	483353.	735444.
10	141675.6	3614461.	1493.	2421.	2389466.	481767.	740807.
11	157071.2	4054875.	1656.	2449.	2661623.	565626.	825177.
12	162453.2	4559042.	1712.	2663.	3054451.	601836.	900091.
13	182126.1	5179821.	1921.	2696.	3443326.	666015.	1067781.
14	173494.1	5007914.	1830.	2737.	3313980.	678668.	1012529.
15	176686.0	5273793.	1862.	2832.	3500756.	727908.	1042296.
16	182505.4	5580369.	1923.	2902.	3694128.	728379.	1154959.
17	182829.4	5504822.	1923.	2863.	3589727.	770045.	1142136.
18	187816.1	5768839.	1980.	2914.	3805102.	807055.	1153767.
19	207958.7	7022137.	2192.	3204.	4638710.	909802.	1470420.
20	198386.3	6733786.	2092.	3219.	4345416.	984961.	1400189.
21	205002.3	6907867.	2162.	3195.	4517910.	961733.	1425027.
22	200953.8	6653753.	2110.	3153.	4395891.	892423.	1362284.
23	192651.6	6391201.	2028.	3151.	4251346.	816233.	1320470.
24	192994.9	6381028.	2033.	3139.	4168226.	860011.	1349651.
25	195487.6	6248892.	2057.	3038.	4037324.	865792.	1342737.
26	194879.2	6481289.	2052.	3159.	4207152.	944398.	1326579.
27	191972.9	6135304.	2023.	3033.	4060885.	821882.	1249503.
28	183984.6	5854133.	1942.	3014.	3783180.	783766.	1284171.
29	177097.2	5314106.	1868.	2845.	3482047.	694134.	1135079.
30	178489.9	5393886.	1882.	2866.	3545290.	727974.	1117755.
31	178560.6	5533151.	1880.	2943.	3617150.	732848.	1180209.
32	200726.5	6525363.	2116.	3084.	4264922.	918978.	1338377.
33	200001.6	6922627.	2105.	3289.	4558080.	920824.	1440432.
34	193617.6	6569891.	2039.	3222.	4320855.	886081.	1359732.
35	208635.4	7244781.	2197.	3298.	4788084.	979381.	1474017.
36	207035.9	7343143.	2178.	3372.	4827998.	1001338.	1510435.
37	193259.2	6115801.	2035.	3005.	4033122.	853507.	1226165.
38	201061.9	6826382.	2114.	3229.	4478803.	965510.	1378838.
39	191872.7	6237976.	2024.	3082.	4058999.	893781.	1282113.
40	196831.5	6749969.	2079.	3247.	4483745.	866879.	1396097.
41	197926.9	6617524.	2085.	3174.	4325987.	942640.	1345721.
42	180421.6	5610279.	1899.	2954.	3737231.	723812.	1146281.
43	194448.2	6045839.	2048.	2952.	4017767.	758682.	1266437.
44	174518.4	5204083.	1839.	2830.	3404302.	741419.	1055531.
45	169164.1	4773370.	1783.	2677.	3110855.	666612.	993225.
46	152475.4	4118246.	1609.	2560.	2710517.	557972.	847197.
47	179300.4	5253649.	1889.	2781.	3468131.	728669.	1054067.
48	162353.3	4401444.	1714.	2568.	2878657.	606033.	914185.
49	166139.0	4439487.	1745.	2544.	3019863.	567358.	849735.
50	168149.3	4603739.	1775.	2594.	3057920.	609509.	933716.
51	151297.1	4055037.	1595.	2542.	2697425.	538977.	816092.
52	164510.5	4650717.	1736.	2679.	3048684.	632240.	967113.

***** RUN NO. 4 *****

YEAR = 1970

NUMBER OF ROUTES = 62

NUMBER OF ALTERNATIVES = 3

ALTERNATIVE NO. 1 -- INCINERATOR

ALTERNATIVE NO. 2 -- SOUTH SIDE DUMP

ALTERNATIVE NO. 3 -- BEVERLY DUMP

ALTERNATIVE NO.	1	2	3
CAPACITY OF SITE (LB/WK)	-1.0	-1.0	-1.0
COST PER MIN. COLLECTION	1.0000	1.0000	1.0000
TREATMENT COST PER LOAD	0.0	0.0	0.0
WAITING TIME (MIN/LD)	25.92	20.32	20.32
LOAD CAPY COMPARED TO STD	1.00	1.00	1.00
COLL.TIME/LD COMP. TO STD	1.00	1.00	1.00

TOTAL FOR YEAR IS -

TOTAL COST = 9249603.0

TOTAL WEIGHT = 280967168.0

TOTAL LCADS = 97475.0

AVERAGE DENSITY = 2882.5

TOTAL WEIGHT TO ALTERNATIVE NO.1 = 184849984.0

NO.2 = 38155088.0

NO.3 = 57814064.0

** COMMENTS **

1 - IF CAPACITY OF SITE = -1 ,SITE CAPACITY IS UNLIMITED.

2 - TOTAL COST IS GIVEN IN TOTAL CREW AND VEHICLE MINUTES.

3 - WEIGHT IS GIVEN IN POUNDS,DENSITY IN LB/LD.

***** RUN NO. 4 *****

ROUTE	LD/YR	TO SITE NO.	1	2	3
1	1021.0		1021.0	0.0	0.0
2	1087.0		1087.0	0.0	0.0
3	1171.0		1171.0	0.0	0.0
4	1476.0		1476.0	0.0	0.0
5	1236.0		1236.0	0.0	0.0
6	1582.0		1582.0	0.0	0.0
7	1814.0		1814.0	0.0	0.0
8	1388.0		1388.0	0.0	0.0
9	1280.0		1280.0	0.0	0.0
10	1559.0		1559.0	0.0	0.0
11	1333.0		1333.0	0.0	0.0
12	1303.0		1303.0	0.0	0.0
13	1496.0		1496.0	0.0	0.0
14	1670.0		1670.0	0.0	0.0
15	1445.0		1445.0	0.0	0.0
16	1769.0		1769.0	0.0	0.0
17	1544.0		1544.0	0.0	0.0
18	1837.0		1837.0	0.0	0.0
19	1988.0		0.0	0.0	1988.0
20	1317.0		0.0	0.0	1317.0
21	1633.0		0.0	0.0	1633.0
22	1378.0		0.0	0.0	1378.0
23	1484.0		1484.0	0.0	0.0
24	1367.0		0.0	0.0	1367.0
25	1245.0		1245.0	0.0	0.0
26	1446.0		1446.0	0.0	0.0
27	1379.0		1379.0	0.0	0.0
28	1909.0		0.0	0.0	1909.0
29	1604.0		0.0	0.0	1604.0
30	1294.0		1294.0	0.0	0.0
31	1665.0		1665.0	0.0	0.0
32	1453.0		1453.0	0.0	0.0
33	1731.0		1731.0	0.0	0.0
34	1708.0		1708.0	0.0	0.0
35	1688.0		1688.0	0.0	0.0
36	1404.0		1404.0	0.0	0.0
37	1458.0		1458.0	0.0	0.0
38	1651.0		1651.0	0.0	0.0
39	2043.0		0.0	2043.0	0.0
40	2155.0		2155.0	0.0	0.0
41	2108.0		2108.0	0.0	0.0
42	1865.0		1865.0	0.0	0.0
43	1738.0		1738.0	0.0	0.0
44	1808.0		0.0	1808.0	0.0
45	1594.0		0.0	1594.0	0.0
46	2187.0		2187.0	0.0	0.0
47	1895.0		1895.0	0.0	0.0
48	1831.0		1831.0	0.0	0.0
49	1548.0		0.0	0.0	1548.0
50	1722.0		0.0	0.0	1722.0
51	2007.0		2007.0	0.0	0.0
52	2652.0		0.0	0.0	2652.0
53	1699.0		0.0	1699.0	0.0
54	2059.0		0.0	2059.0	0.0
55	1186.0		0.0	1186.0	0.0
56	1356.0		0.0	1304.0	0.0
57	1539.0		0.0	1539.0	0.0
58	1543.0		0.0	0.0	1543.0
59	1385.0		0.0	0.0	1385.0
71	1251.0		1251.0	0.0	0.0
72	1193.0		1193.0	0.0	0.0
73	298.0		298.0	0.0	0.0

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